ON THE

STRENGTH OF CEMENT.

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EXPERIMENTS

ON THE

STRENGTH OF CEMENT,

CHIEFLY IN REFERENCE TO THE PORTLAND CEMENT USED IN THE SOUTHERN MAIN DRAINAGE WORKS.

BY

JOHN GRANT, M. INST. C.E.

THESE PAPERS WERE ORIGINALLY PRESENTED TO THE INSTITUTION OF CIVIL ENGINEERS AND READ AT THE MEETINGS OF THE SOCIETY, SESSIONS 1865–6 AND 1870–1, AND ARE NOW REPRINTED BY PERMISSION OF THE COUNCIL.

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PREFACE.

THE first of the following Papers on Cement was read before the Institution of Civil Engineers, London, in December, 1865; the second in April, 1871. Both have been out of print for some time, the first for several years; and as frequent inquiries are being made for them, it has been considered advisable to reprint them, the Council of the Institution having very kindly given their permission.

Nothing has occurred since these Papers were read to invalidate the facts or make it necessary to modify the statements made by the Author, who hopes that they may form a safe starting point for anyone who wishes to pursue the subject farther.

INDEX.

EXPERIMENTS ON THE STRENGTH OF CEMENT.[1]

SINCE the formation of the Metropolitan Board of Works, about ten years ago, the great system of drainage for the metropolis, recently described in Mr. Bazalgette's Paper,[2] has been designed and executed. The Author, who superintended that portion of the scheme which lies south of the Thames, believes that the following description of the means adopted to ensure the use of cement of the best quality only, in these works, may not be without benefit or interest to the members.

Previous to 1859 Roman cement was, with few exceptions, the only cement used for the inverts of the London sewers, the arches being set in blue lias lime, and Portland cement scarcely ever tried. In view, however, of these large works, the Author, about the end of the year 1858, commenced an extensive series of experiments upon bricks, cements, and other materials. Portland cement had, in this country, been chiefly confined to ordinary building operations, such as external plastering, and to some harbour works on the southern coast and in the Channel Islands, where it was mostly used in the form of concrete blocks.

In France, and in other parts of Europe, large harbour and dock works had been constructed with Portland cement, made in England, and the tests employed, which were generally of a searching, though in some respects tedious, character, no doubt

[1] The discussion upon this Paper extended over portions of four evenings, but an abstract of the whole is given consecutively.

[2] *Vide* 'Minutes of Proceedings Inst. C.E.,' vol. xxiv.

prepared the principal manufacturers of this country for the production of cement suitable for works like those then contemplated for the drainage of London.

As a preliminary step, for the purpose of experiments, applications for samples were made to the leading manufacturers of Portland cement, and Tables I. II. III. and IV. of the Appendix give the result of the tests to which they were subjected. The names of the makers of these earlier samples have been omitted, as it might be considered invidious to compare one producer with another, especially as some of the samples forwarded for experiment were, avowedly, specially prepared. Other specimens were subsequently obtained from various makers, in the ordinary way, without mentioning the purpose for which they were required; and the results obtained, though they widely disagreed, were sufficiently satisfactory to warrant the insertion of the following clause, in the specification for the Southern High-Level Sewer (1859), being the first contract on the south side of the river Thames:—

"The whole of the cement to be used in these works, and referred to in this specification, is to be Portland cement, of the very best quality, ground extremely fine, weighing not less than 110 lbs. to the striked bushel, and capable of maintaining a breaking weight of 400 lbs. on an area $1\frac{1}{2}$ inch $\times$ $1\frac{1}{2}$ inch, equal to $2\frac{1}{4}$ square inches, seven days after being made in an iron mould, of the form and dimensions shown on drawing No. 1 (Plate 2), and immersed six of these days in water." The Board having adopted this test, attention was next turned to devising some safe and ready mode of practically applying it with accuracy. For this purpose, moulds were made of bell-metal, having a sectional area, at the breaking point, of $1\frac{1}{2}$ inch $\times$ $1\frac{1}{2}$ inch $=$ $2\frac{1}{4}$ square inches, with templates of thin iron, exactly fitting the mould, so that, with the aid of a simple machine, the bricks could be pressed out shortly after the mould had been filled. The machine devised for showing the tensile strain was a lever balance (Plate 5), very accurately constructed by Mr. P. Adie (Assoc. Inst. C.E.). The whole apparatus was fixed in testing houses on the works, and access to these premises could only be obtained through the proper officers. The machines used for testing have since, in several cases, been adopted by the manufacturers at their own works, an acknow-

ledgment of the soundness of the principle, and of its adaptability to the requirements of this manufacture. No difficulty was experienced in training an ordinary workman to test the cement by means of these machines; and after using, during the last six years, more than 70,000 tons of Portland cement, which has been submitted to about 15,000 tests, it can be confidently asserted, that none of an inferior or dangerous character has been employed in any part of the works in question.

In the construction of branch sewers it has, in many cases, been necessary to cut through main sewers, and specimens of the materials are submitted, to show the perfect adhesion between the bricks and the cement.

During the preliminary experiments objection was taken to the standard then proposed, and afterwards adopted, and it was strongly urged that a standard of 300 lbs., instead of 400 lbs., would be found, in practice, to be the highest attainable. But, fortunately for the cement trade itself, not only was the higher standard established, but, in subsequent specifications, it was increased. After the first start, little difficulty was experienced in obtaining Portland cement of standard quality. A few of the earliest deliveries were rejected, but subsequently the makers of them regained their position; and the Author feels bound to express his thanks to those who so materially assisted, by the excellence of their manufacture, in obtaining such satisfactory results. While aiming at a high quality of cement, the necessity of sufficiently remunerating the manufacturer was not lost sight of; and, in the first schedule of prices, 2*s.* 3*d.* per bushel was the price inserted. This, however, is much above its present market value.

Though the use of Portland cement had been comparatively limited, the extensive adoption of this material in the construction of the metropolitan sewers drew the attention of engineers and contractors to its value and importance; and it may be safely assumed, that during the progress of these works double the quantity of this cement has been used in London which has ever been employed, in the same time, since its first introduction or discovery.

Roman cement is, under certain conditions, useful, but in works of importance, even with the adoption of precautionary

measures to ensure purity and freshness, its strength is much inferior to Portland cement. Besides its inherently weaker character, Roman cement has the great practical disadvantage of losing its strength by being kept long before use, or by being exposed to the air; whereas Portland cement improves by being kept and by exposure to the air, provided it be kept dry.

No reference will be made in this Paper to the chemical properties of Portland cement, or to any theories as to the admixture, in its manufacture, of one material with another in various proportions. These points have already been so fully treated by Members of the Institution and by different foreign authors, as to have rendered familiar at least the prominent features of limes and cements.

The manufacture of Portland cement is not one of complex character, although it requires the exercise of extreme care in the admixture of its two simple and well-known ingredients, clay and chalk. This cement is almost solely manufactured on the rivers Thames and Medway, and the clay is obtained from the creeks and bays between Sheerness and Maidstone. Much care is required in the selection of the clay, so that it shall be as free from sand as possible; and the proportion in which it is used depends altogether on the quality of the chalk with which it is to be incorporated. In the white chalk districts the clay forms from 25 per cent. to 30 per cent. of the whole bulk, and in the grey chalk districts the proportion of clay varies from 16 per cent. to 20 per cent. Both districts have contributed to the satisfactory results recorded in the accompanying Tables.

Experience in the daily use of Portland cement has enabled the clerks of the works and others to judge, generally by colour and by weight, of its quality; and many of the bricklayers who have been employed on these works, and who had previously a very imperfect acquaintance with this cement, or with its peculiar properties, have now acquired confidence and experience in using it, which will be valuable hereafter on other works upon which they may be engaged. It is not to be expected that, in ordinary small building operations, the necessary testing, though simple and inexpensive, will be maintained. In such cases the precaution must be taken of employing respectable manufacturers,

who have the means of thoroughly testing the cement made by them, and who can confidently guarantee its quality. If proper care had been exercised, many buildings would have been saved the disfigurement caused by the blowing or cracking of the cement with which they are covered. In all works of magnitude, engineers and architects should insist upon the cement being thoroughly tested before being used. To do so no great expense need be incurred; for the first cost of one of the machines is about 50*l*., and the annual charge for labour about 80*l*. The whole expense of testing the cement used in these works, which extend over a district eighteen miles in length, and cost upwards of 1,250,000*l*., has only been about five farthings per ton of cement ; an utterly insignificant cost, when compared with the great advantages gained in quality and in soundness of work.

It was at first intended that the tests should be confined to the simple requirements of the works, and it was not contemplated further to extend the observations and experiments. The facilities, however, which were afforded for the successful investigation of so interesting and useful a subject, induced the Author not only to keep an accurate record of all the ordinary tests, but to extend his inquiry into other points, the results of which are shown in No. XVI. and following Tables.

Although the testing apparatus will indicate the strength of the cements, it must not be inferred that it renders unnecessary all supervision afterwards. Among the more important points requiring attention are, the quality of the sand to be mixed with the cement, and the thorough saturation of the bricks, so that, in setting the cement may not be robbed, by absorption, of the moisture necessary for its perfect hardening. Instances have occasionally occurred where, in consequence of negligence on the part of the workmen, imperfect adhesion of the cement to the bricks has resulted. Great care is also necessary to prevent any current of water from passing over the cement, or through the joints, during the process of setting, as this would wash away the soluble silicates, which form a necessary element in the cement. The drainage works were protected from this danger by stoneware pipes laid under the invert of the sewer, so as to carry off the water while the brickwork was in progress. In concrete this must be specially guarded against, although

the risk would be much reduced by the use of a cement of less specific gravity, which would set more quickly. In some cases even Roman cement could be advantageously employed for such purposes.

Tables I. II. III. and IV. may be considered the first of the series, and their only value consists in showing how precarious and irregular the quality of Portland cement was at that time. Some of the irregularity in the results may be attributed to the imperfect apparatus used at that early stage; but this was of course avoided subsequently by the adoption of the new apparatus.

Tables I. II. and III. show an average weight of 108·6 lbs. per bushel, and an average breaking, or tensile strain, varying from 75 lbs. to 719 lbs. on $2\frac{1}{4}$ square inches. The adoption of this particular size was, to some extent, obligatory, from its being the only known form of mould in use. It is intended, however, to substitute a mould with sectional area of 4 square inches (Plate 3), and of a somewhat different form.[1]

The importance of having the cement finely ground was shown very early in these experiments; and there can be no doubt that much of the difference in these first results is attributable to the several samples varying greatly in this respect. At the same time, it was also manifest that the cement, when carefully moistened, and only supplied with sufficient water to reduce it to a state of paste, gave better results than when unduly charged with water. The best method for applying water is by a perforated nozzle at the end of a pipe or watering-can. It should be stated that in every case the shape and sectional area of the mould were the same, viz. $1\frac{1}{2}$ inch $\times$ $1\frac{1}{2}$ inch $= 2\frac{1}{4}$ square inches. Where not otherwise stated, the samples were immersed in water from the time of setting to the time of testing; and the results are, as a rule, the average of ten tests. Whilst setting, each sample was numbered at both ends, and recorded in duplicate, in registers, of which the form is given in the Appendix.

The means adopted to obtain accurate results having been described, and reference having been made to the earlier of

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[1] Later experience has shown that the original size, with form slightly modified, is preferable.—J. G.

these, as set forth in Tables I. to IV., attention will now be drawn to Tables V. to XV. inclusive, which give the strength, as tested by tensile strain, of 1,369,210 bushels of the Portland cement used in the drainage works on the south side of the Thames, between the years 1859 and 1865.

These Tables, of which V. and VI. are summaries, give the names of the manufacturers, the quantity supplied by each, the weight per bushel, the average breaking weight, and the specified standard. The tests have been 11,587 in number, and the general results are, that the cement supplied to these works has weighed, on an average, 114·15 lbs. per bushel, and has borne a tensile strain of 606·8 lbs., equal to 270 lbs. per square inch; whilst the specifications required a weight of 110 lbs. per bushel, and a tensile strength of 400 lbs. in the first instance, and afterwards of 500 lbs. Thus the cement has been 51½ per cent. above proof, in the first case, and 21 per cent. in the second.

Besides these daily tests of the strength of the cement supplied for the works, further experiments were made on the strength of cement by itself, and with different proportions and different kinds of sand, at periods varying from one week to twelve months.

Table XVI. gives the results of 370 experiments with Portland cement, weighing 112 lbs. to the imperial bushel, gauged neat, and with different proportions of various kinds of sand. The neat cement bore, at the end of a week, 558·5 lbs.; at the end of twenty-eight days, 784·5 lbs.; at the end of six months, 960·8 lbs.; and at the end of twelve months, 1009·8 lbs. Mixed with an equal proportion of clean Thames sand, the breaking weight, at the end of a week, was 190·7 lbs.; at twenty-eight days, 373·5 lbs.; at six months, 603·2 lbs.; and at twelve months, 724 lbs. It will be observed that at the end of a week the strength is only 34·1 per cent. of neat cement; at the end of a month, 47·6 per cent.; at six months, 62·8 per cent.; and at twelve months, 71·7 per cent. When mixed with Thames sand, in the proportion of 1 of cement to 3 of sand, the breaking weights were, respectively, 62 lbs., 108 lbs., 308·1 lbs., and 371·1 lbs., at the end of a week, one month, six months, and twelve months; that is, 11·1, 13·8, 32·1, and 36·7 per cent. of the strength of neat cement. When mixed with

the same sand, in the proportion of 1 to 4, the breaking weights at one month, six months, and twelve months respectively were 90·5 lbs., 149 lbs., 198·2 lbs.; or, 11·54, 15·5, and 19·62 per cent. of the strength of neat cement. When mixed with the same sand, in the proportion of 1 to 5, the breaking weights were 43 lbs. at one month, 122·5 lbs. at six months, and 204·4 lbs. at twelve months; or, 5·48, 12·75, and 20·24 per cent. of neat cement. The next column gives the breaking weight of the same cement mixed with another sample of Thames sand, in equal proportions. The results were 213·1 lbs. at a week, 418 lbs. at a month, 614·5 lbs. at six months, and 757·9 lbs. at twelve months; or, from 2 per cent. to 12 per cent. more than in the first case. The next two columns give the breaking weight of the same cement, when mixed with very clean pit sand, taken from the excavations. These results were somewhat higher than with either of the samples of Thames sand, being with a proportion of 1 to 1227·8 lbs. at a week, 423·1 lbs. at a month, 625·9 lbs. at six months, and 815·4 lbs. at twelve months. The last being 12·6 per cent. above the first, and 7·71 per cent. above the second sample of Thames sand. The next two columns give the breaking weight of the same cement, with an inferior, or loamy pit sand, in the proportion of 1 to 1. The strength, at a week, was 166·8 lbs., and at a month 376·9 lbs.; the latter being very nearly the same as the first sample of Thames sand = 373·5 lbs. When mixed with 2 parts of sand, the breaking weight, at a month, was 251·5 lbs., or 11·4 per cent. above the first-mentioned Thames sand. The last two columns show the breaking weight of the same cement when mixed with an equal quantity of the last-mentioned pit sand, washed; the result being 223·9 lbs. at a week, and 364·9 lbs. at a month. The washing of the sand seems to add about 35 per cent. to the strength at the end of a week; but at the end of a month this experiment is not so satisfactory. With washed pit sand, in the proportion of 1 of cement to 2 of sand, the breaking weight, at twenty-eight days, was 330 lbs., or 46·2 per cent. above the first specimen of Thames sand, or 31·21 per cent. above the same sand, when not washed.

Table XVII. gives the results of 960 experiments as to the breaking weight of Portland cement weighing 112 lbs. to the bushel, gauged neat, and also with different proportions of

Thames, clean pit, and loamy sands. When gauged neat the cement bore :—

	lbs.
1 week	445·0
1 month	679·9
3 months	877·9
6 „	978·7
9 „	995·9
12 „	1075·7

Thus in three months the cement bore about double the strain it did at the end of a week, and at the end of twelve months, 241·70 per cent., or nearly twice and a half the strain that it bore at the end of a week. These results agree, in the main, with those of the last Table, although the cement seems to have been somewhat slower in setting, breaking at 445 lbs. against 558·5 lbs. at the end of a week; but overtaking the first set at the end of six months, and at twelve months being 1075·7 lbs. against 1009·8 lbs., or having 6·5 per cent. greater strength. The next five columns give the breaking weights of the same cement mixed with clean, sharp, Thames sand, in proportions varying from 1 to 1, to 1 to 5.

When mixed with an equal proportion of sand, the breaking weights are at:—

	lbs.		Per cent. of the strength of neat Cement.
1 week	97·0	=	21·8
1 month	309·3	=	44·5
3 months	367·0	=	41·8
6 „	546·8	=	55·9
9 „	607·8	=	61·3
12 „	700·3	=	65·1

When mixed with twice the proportion of sand, the breaking weights are at:—

	lbs.		Per cent. of the strength of neat Cement.
1 week	52·5	=	11·80
1 month	123·5	=	18·16
3 months	254·5	=	29·00
6 „	425·1	=	43·46
9 „	431·5	=	43·33
12 „	458·5	=	42·62

When mixed in the proportion of 1 of cement to 3 of sand, the breaking weights are at :—

	lbs.		Per cent. of the strength of neat Cement.
1 week	27·0	=	6·07
1 month	58·0	=	8·53
3 months	135·5	=	15·43
6 „	232·4	=	23·74
12 „	320·6	=	29·90

When mixed in the proportion of 1 of cement to 4 of sand, the breaking weights are at :—

	lbs.
1 month	32·5
3 months	109·0
6 „	157·0
12 „	221·6

When mixed in the proportion of 1 of cement to 5 of sand, the breaking weights are at :—

	lbs.
1 month	21·0
3 months	88·5
6 „	95·5
12 „	122·3

The next five columns show the breaking weights of the same cement, mixed with similar proportions of clean pit sand taken from the excavations. The strength is, in every case, much greater than in the corresponding columns just described, where Thames sand was used. The succeeding five columns, giving similar particulars with a loamy pit sand, correspond more with the first five, where Thames sand was used, and show the importance of attending to the quality of the sand, especially where the proportions of sand vary. Looking down the three columns which give the breaking weights with equal proportions of cement and sand, it will be perceived that the strength rapidly gains in proportion upon that of the neat cement. Thus, in the first case, that which was only 21·8 per cent. at

the end of a week, and 45·5 per cent. at the end of a month, at the end of the year has increased to 65·1 per cent. of the strength of neat cement. With clean pit sand the corresponding column 1 to 1 shows that the gain is much greater, increasing from 34·2 per cent. at the end of a week, to 74·0 per cent. at the end of a year. Again, if the breaking weights at twelve months, in the three sets of columns for the proportions of cement to sand of 1 to 2, 1 to 3, and 1 to 4, are multiplied by 2, 3, and 4 respectively, on the average it will be found that the normal strength of the neat cement (1075·7 lbs.) is, as nearly as possible, diluted in proportion to the quantity of sand, the average numbers being 1066·1 lbs., 1103·4 lbs., and 1044·8 lbs. This, however, does not hold good with the proportion of 5 of sand to 1 of cement, except where the sand is purest; the strength at the end of twelve months, multiplied as before by 5, being 611·5 for Thames sand, 1078 for clean pit sand, and 831 for loamy pit sand, against 1075·7, the normal strength of the neat cement.

The foregoing experiments, extending only to twelve months, still left some interesting points unsettled; as, for instance, the age at which cement, whether neat or mixed with sand, ceases to increase in strength; the age at which the several compounds of cement and sand approach nearest to the normal strength of neat cement, or, in other words, obtain their maximum strength; also, the most economical proportion of cement and sand, with an assumed minimum strength. The last point has been approximately ascertained by the Table just referred to, inasmuch as it has been shown that with sand in the proportion of 2, 3, and 4 to 1 of cement, the sand simply acts as a diluting agent; but with sand in the proportion of 5 to 1 of cement, any imperfection in the sand materially affects the strength of the compound. Thus it is only with clean pit sand that the full strength of the cement is obtained; the strength, 215·6, multiplied by 5, gives 1078 lbs. against 1075·7 lbs., the strength of the neat cement.

With the view of ascertaining, if possible, the age at which cement mixed neat and with sand attains its greatest strength, another series of 300 experiments, intended to extend over ten years, was commenced, but at present only those for the first three years, 160 in number, can be given (Table XVIII.).

The cement in this case weighed 123 lbs. per imperial bushel. The breaking weights of the neat cement are at:—

	lbs.
1 week	817·1
1 month	935·8
3 months	1055·9
6 „	1176·6
9 „	1219·5
12 „	1229·7
2 years	1324·9
3 „	1314·4

The same cement when mixed with an equal proportion of Thames sand broke at the following weights:—

	lbs.		Per cent. of neat Cement.
1 week	353·2	=	40·78
1 month	452·5	=	48·35
3 months	547·5	=	51·85
6 „	640·3	=	54·42
9 „	692·4	=	56·77
12 „	716·6	=	58·27
2 years	790·3	=	59·65
3 „	784·7	=	59·70

The proportionate strength of cement and sand increases, it will be perceived, between three months and twelve months, at the rate of 2 per cent. every three months, but in the course of the second year only 1·38 per cent. per annum. In the third year there is no increase.

Table XIX. gives the result of 225 experiments, made with cement gauged neat and kept for periods varying from seven days to twelve months, first, in water; secondly, out of water, in-doors; and thirdly, out of water, exposed to the action of the weather. At the end of twelve months the results are respectively as 1099, 827·4 and 719·6; that is to say, the cement which was kept out of water in-doors attained only 75·29 per cent. of the strength of that which was kept in water; while that which was out of water, and exposed out of doors, acquired only 65·48 per cent. As there are considerable

variations in the apparent strength at different ages, if the averages are taken, they are as 100, 80·64, and 76·8. Cement allowed to set under water seems, from these experiments, to gain strength from 24 per cent. to 30 per cent.

Tables XX. and XXI. give the relative strength of cement gauged with fresh water and with salt water, at various ages, from a week to five months. The difference, though not very material, is in favour of salt water. This is satisfactory, as in the case of harbours, docks, and piers, where the water is either salt or brackish, there need be no hesitation in using salt water, either in making Portland cement concrete or in building.

Tables XXII. to XXVII. inclusive show the results of 685 experiments made with Roman cement. The only inferences to be drawn from these are, that the best Roman cement is very inferior to Portland, especially when mixed with sand.

Table XXVIII. gives the strength of Keene's cement and Parian cement, in water and out of water, for periods varying from seven days to three months. At three months the strength of Keene's cement in water is 508·8 lbs.; out of water, 720·5 lbs.; or 41 per cent. more. Parian cement in water, 521 lbs.; out of water, 853·7 lbs.; or 64 per cent. more.

Table XXIX. gives the strength of Medina cement at various periods, from seven days to two years, the increase being from 211 lbs. at seven days, to 476·9 lbs. in twelve months, and 276 lbs. in two years. There is a great falling off in the second year.

These three cements have only been used for internal architectural purposes.

Table XXX. gives the number of tons required to crush bricks made of Portland cement neat, and with five different proportions of sand at three, six, and at nine months, at which different periods the strength of the neat cement bricks was 65 tons, 92 tons, and 102 tons respectively, or more than that of Staffordshire blue bricks. Bricks made of a mixture of sand with cement, in the proportions of 4 to 1 and 5 to 1, stand a pressure equal to the best stock bricks.

Tables XXXI. to XXXIV. give the results of about 300 experiments on the strength of different kinds of bricks.

Table XXXV. shows the strength of blocks of Portland,

Bramley Fall stone, and York stone landings, of the same size as an average brick. Portland stone, on its bed, bears a crushing weight of 47 tons, on an area of about 40 square inches, equal to 2631 lbs. per inch; and against its bed it bears somewhat less. Bramley Fall, on its bed, bears $91\frac{1}{3}$ tons, equal to 5122 lbs. per square inch, or nearly double that of Portland; and against its bed it bears $52\frac{2}{3}$ tons, or 2953 lbs. per square inch.

The following is a recapitulation of the results of the tests and experiments shown in the annexed Tables, and of such facts as have come under observation:—

1st. The earlier experiments, made six years ago (Tables I. to IV.), gave, at the end of a month, a breaking weight varying from 75 lbs. to 719 lbs. on an area of $2\frac{1}{4}$ square inches.

2nd. A minimum test of at first 400 lbs., and afterwards of 500 lbs., was specified.

3rd. During six years the average strength of 1,369,210 bushels used in the Southern Main Drainage works has been 606·8 lbs. (Tables V. and VI.), being 52 per cent. above the standard first specified, and 21 per cent. above that subsequently adopted.

4th. The average weight per bushel has been 114·15 lbs., being 4·15 per cent. above the specified standard.

5th. Portland cement has been proved to be peculiarly suitable for hydraulic works, and may be procured in any quantity, and of the highest quality.

6th. Portland cement, if it be preserved from moisture, does not, like Roman cement, lose its strength by being kept in casks or sacks, but rather improves by age; a great advantage in the case of cement which has to be exported.

7th. The longer it is in setting, the more its strength increases. (Tables XVIII. and XIX.)

8th. Neat cement is stronger than any admixture of it with sand.

9th. Cement mixed with an equal quantity of sand (as has been the case throughout the Southern Main Drainage works), may be said to be, at the end of a year, approximately three-fourths of the strength of neat cement.

10th. Mixed with 2 parts of sand it is half the strength of neat cement.

11th. With 3 parts of sand the strength is a third of neat cement.

12th. With 4 parts of sand the strength is a fourth of neat cement.

13th. With 5 parts of sand the strength is about a sixth of neat cement. (Table XVII.)

14th. The cleaner and sharper the sand, the greater the strength.

15th. Very strong Portland cement is heavy, of a blue-grey colour, and sets slowly. Quick-setting cement has generally too large a proportion of clay in its composition, is brownish in colour, and turns out weak, if not useless.

16th. The stiffer the cement mortar, that is, the less the amount of water used in working it up, the better.

17th. It is of the greatest importance that the bricks or stone with which Portland cement is used should be thoroughly soaked with water. If under water in a quiescent state, the cement will be stronger than out of water. Table XIX. shows that cement kept in water was one-third stronger than that kept out.

18th. Blocks of brickwork or concrete made with Portland cement, if kept under water till required for use would be much stronger than if kept dry.

19th. Salt water is as safe for mixing with Portland cement as fresh water.

20th. Bricks made with neat Portland cement are as strong at from six months to nine months as the best quality of Staffordshire blue bricks, or similar blocks of Bramley Fall stone or Yorkshire landings.

21st. Bricks made of 4 parts or 5 parts of sand to 1 part of Portland cement will bear a pressure equal to the best picked stocks.

22nd. Portland cement concrete, made in the proportions of 1 of cement to 8 of ballast, in some cases, and of 1 to 6 in others, has been extensively used for the foundations of the river wall, piers of reservoirs, and foundations generally, at Crossness and Deptford, with the most perfect success; and it is believed that it might be much more extensively used as a substitute for brickwork or masonry wherever skilled labour, stone, or bricks are scarce, and foundations are wanted at the least expenditure of time or money.

23rd. Wherever concrete is used under water, care must be taken that the water is still; as otherwise a current, whether natural or caused by pumping, will carry away the cement and leave only the clean ballast.

24th. Roman cement, though about two-thirds the cost of Portland, is only about one-third its strength, and is therefore double the cost, measured by strength.

25th. Roman cement is very ill adapted for mixing with sand.

In conclusion, whilst recommending Portland cement as the best article of the kind that can be used by the Engineer or the Architect, the Author would warn anyone against its use who is not prepared to take the trouble or incur the trifling expense of testing it; as if manufactured with improper proportions of its constituents—chalk and clay—or improperly burnt, it may do more mischief than the poorest lime.

Further experiments are desirable on the strength of adhesion between bricks and cement under varying circumstances; on the limit to the increase of strength with age; on the relative strength of concrete made with various proportions of cement and ballast; and on the use of cement in very hot climates, where, probably, extra care will be required in preserving the cement from damp, and in keeping it cool, until the process of setting has been completed. On these and other points it is trusted that all who have the opportunity will make a record of their observations, for presentation to the Institution. Great credit is due to those manufacturers who have produced the high quality of cement (from 20 per cent. to 50 per cent. above the specified strength), shown in Table VI.

APPENDIX.

Table I.

Abstract of 70 Experiments with Portland Cement, mixed neat, and immersed in water, for seven and fourteen days. January, 1859.

Manufacturer.	Weight per Bushel.	In Moulds 7 Days.		In Moulds 14 Days.	
		No. of Experiments.	Average Breaking Tests.[1]	No. of Experiments.	Average Breaking Tests.[1]
	lbs.		lbs.		lbs.
A	113	1	663	2	691
B	109	8	335	4	525
C	112	1	518	2	502
D	112	5	397	5	485
	103	7	373	8	464
E	110	6	371	4	465
F	110	1	299	2	355
G	109	1	299	2	334
H	106	6	294	3	313
I	83	2	215	..	..
Average ..	106·7	38	354·61	32	462·5

Table II.

Table of the Results of 200 Experiments with Portland Cement, mixed neat, and immersed in water for seven days, made between 12th April and 4th July, 1859.

Manufacturer.	Weight per Bushel.	Breaking Tests.[1]		
		Minimum.	Maximum.	Average.
	lbs.	lbs.	lbs.	lbs.
K	120	313	719	526·75
C	116	327	509	417·50
A	105	327	481	395·90
G	109	187	472	370·15
D	110	187	478	360·40
J	106	187	439	328·15
B	105	131	383	318·90
H	107	75	540	315·80
E	102	75	404	251·70
F	96	175	318	237·50
Average ..	107·6	198·4	474·3	352·27

[1] Sectional area, 2·25 square inches.

Table III.

Table of the Results of 17 Experiments with Portland Cement, mixed neat, and immersed in water for seven days. March, 1859.

Manufacturer.	No. of Experiments.	Weight per Bushel.	Breaking Tests.[1]		
			Minimum.	Maximum.	Average.
		lbs.	lbs.	lbs.	lbs.
K	2	120	635	719	677·0
L	2	104	509	546	527·5
D	3	112	453	551	499·6
A	2	113	383	489	436·0
C	2	112	383	467	425·0
B	2	109	405	419	412·0
G	2	114	306	327	315·5
E	2	110	299	327	313·0
Average ..	17	111·75	421	484	453·68

Table IV.

Table of the Results of 15 Experiments with Portland Cement, mixed with an equal proportion of sand, and immersed in water for seven days. 3rd to 10th March, 1859.

Manufacturer.	No. of Experiments.	Weight per Bushel.	Breaking Tests.[1]		
			Minimum.	Maximum.	Average.
		lbs.	lbs.	lbs.	lbs.
A	3	113	387	398	392·0
C	3	112	173	187	182·3
E	3	110	159	198	177·3
B	3	109	145	173	163·6
D	3	112	117	131	121·6
Average ..	15	111·2	195·4	217·4	207·4

[1] Sectional area, 2·25 square inches.

TABLE V.

METROPOLITAN MAIN DRAINAGE.

CONTRACTS ON THE SOUTH SIDE.

SUMMARY OF TABLES VII. to XV. inclusive.

PORTLAND CEMENT, Seven Day Tests, from 1859 to 1865.

NAME OF CONTRACT.	Quantity in Bushels.	Average Weight per Bushel.	Number of Tests.	Average Breaking Tests.[3]	Specified Standard Test.[3]
		lbs.		lbs.	lbs.
Southern High-Level Sewer[2] (VII.)	148,728	119·04	1,532	558·07	400
St. George's Wharf (VIII.) ..	6,791	113·28	222	436·56	..
Southern Outfall Sewer[1] (IX.) ..	391,405	110·96	3,350	550·62	..
Deptford Pumping Station (X.)	83,714	111·63	740	486·75	..
Southwark Improvement (XI.) .	39,212	117·39	600	672·14	400 & 500
Southern High-Level Extensions (XII.)	50,443	113·81	780	626·81	400
Bermondsey Branch (XIII.) ..	78,492	119·07	690	688·27	500
Southern Outfall Works[1] (XIV.)	349,620	113·57	2,097	692·99	..
Southern Low-Level Sewer[1] (XV.)	220,805	114·15	1,576	668·79	..
Generally	1,369,210	114·15	11,587	606·80	..

TABLE VI.

METROPOLITAN MAIN DRAINAGE.

CONTRACTS ON THE SOUTH SIDE.

SUMMARY OF TABLES VII. to XV. inclusive.

PORTLAND CEMENT, Seven Day Tests, from 1859 to 1865.

NAMES OF MANUFACTURERS AND AGENTS.	Quantity in Bushels.	Average Weight per Bushel.	Number of Tests.	Average Breaking Tests.[3]	Specified Standard Test.[3]
		lbs.		lbs.	lbs.
Mr. Robins	128,467	119·43	1,423	670·67	400
Burham Brick and Cement Company (Mr. Webster)[1] ..	938,322	112·89	7,023	631·09	400 & 500
Messrs. Lee and Co.[2]	99,450	120·03	962	612·85	400
Messrs. E. Bow and Co. (Agents)	1,000	..	10	546·80	..
Messrs J. B. White & Brothers	34,430	109·13	327	544·18	..
Mr. Hilton	27,788	114·17	510	511·01	..
Messrs. Knight and Co.	69,358	112·66	574	500·53	..
Mr. Smeed	44,241	111·85	423	452·36	..
Mr. Wood (Agent)	3,600	107·83	102	444·50	..
Messrs. Cubitt and Co.	..	112·00	6	409·11	..
Mr. Buckwell (Agent)	1,400	100·00	3	408·50	..
Messrs. Fletcher & Co. (Agents)	20,154	118·00	179	394·03	..
Messrs. Francis Brothers	1,000	105·66	31	328·22	..
Mr. Tatham (Agent)	..	106·00	14	184·71	..
Generally	1,369,210	114·15	11,587	606·80	..

[1] Mr. Webster was the Contractor for the erection of two-thirds of the works embraced in Tables V. and VI.

[2] Wm. Lee, Esq., M.P., was the Contractor for the Southern High-Level Sewer.

[3] Sectional area, 2·25 square inches.

TABLE VII.

METROPOLITAN MAIN DRAINAGE.

SOUTHERN HIGH-LEVEL SEWER.

Messrs. LEE and Co., Contractors.

SUMMARY of PORTLAND CEMENT, Seven Day Tests, from 1859 to 1862.

NAME OF MANUFACTURER.	Quantity in Bushels.	Average Weight per Bushel.	Number of Tests.	Average Breaking Tests.[1]
		lbs.		lbs.
Messrs. Lee and Co.	99,300	120·06	952	614·66
Messrs. E. Bow and Co.	1,000	..	10	465·80
Mr. Robins	19,300	120·87	183	544·32
Messrs. Knight and Co.	6,338	118·50	75	541·13
Messrs. Fletcher, Lark, and Co.	18,154	118·50	159	515·15
Mr. Wood	3,600	107·83	102	444·50
Mr. Hilton	36	..	6	426·00
Messrs. Francis Brothers	1,000	105·66	31	328·22
Mr. Tatham	..	106·00	14	184·71
Generally	148,728	119·04	1,532	558·07

[1] Specified standard, 400 lbs.

TABLE VIII.

METROPOLITAN MAIN DRAINAGE.

ST. GEORGE'S WHARF CONTRACT.

Messrs. JOHN AIRD and SON, Contractors.

SUMMARY of PORTLAND CEMENT, Seven Day Tests, from 1860 to 1862.

NAME OF MANUFACTURER.	Quantity in Bushels.	Average Weight per Bushel.	Number of Tests.	Average Breaking Tests.[1]
		lbs.		lbs.
Mr. Hilton	6,500	113·64	202	440·00
Messrs. Knight and Co.	96	105·66	12	408·08
Messrs. J. B. White & Brothers	195	119·00	8	392·50
Total	6,791	113·28	222	436·56

[1] Specified standard, 400 lbs. Sectional area, 2·25 square inches.

TABLE IX.

METROPOLITAN MAIN DRAINAGE.

SOUTHERN OUTFALL SEWER.

Mr. WILLIAM WEBSTER, Contractor.

SUMMARY of PORTLAND CEMENT, Seven Day Tests, from 1860 to 1862.

NAME OF MANUFACTURER.	Quantity in Bushels.	Average Weight per Bushel.	Number of Tests.	Average Breaking Tests.[1]
		lbs.		lbs.
Burham Brick and Cement Company (Mr. Webster)	317,671	111·51	2,726	564·14
Messrs. J. B. White and Brothers	26,280	108·85	179	521·38
Messrs. Knight and Co.	31,888	110·92	247	510·52
Mr. Smeed	10,766	112·18	153	476·65
Messrs. Cubitt and Co.	..	112·18	6	409·11
Mr. Buckwell	1,400	100·00	3	408·50
Mr. Hilton	1,400	111·00	16	402·30
Messrs. Fletcher, Lark, and Co.	2,000	111·00	20	223·10
Generally	391,405	110·96	3,350	550·62

[1] Specified standard, 400 lbs.

TABLE X.

METROPOLITAN MAIN DRAINAGE.

DEPTFORD PUMPING STATION AND GAS WORKS.

Messrs. JOHN AIRD and SON, Contractors.

SUMMARY of PORTLAND CEMENT, Seven Day Tests, from 1860 to 1862.

NAME OF MANUFACTURER.	Quantity in Bushels.	Average Weight per Bushel.	Number of Tests.	Average Breaking Tests.[1]
		lbs.		lbs.
Mr. Robins	1,200	118·00	10	691·40
Mr. Hilton	17,952	115·18	210	545·28
Messrs. Knight and Co.	30,937	109·55	240	482·03
Messrs. Lee and Co.	150	118·00	10	440·90
Mr. Smeed	33,475	111·66	270	438·62
Generally	83,714	111·63	740	486·75

[1] Specified standard, 400 lbs. Sectional area, 2·25 square inches.

TABLE XI.

METROPOLITAN MAIN DRAINAGE.

SOUTHWARK AND WESTMINSTER COMMUNICATION (Southwark Street and Subway).

Messrs. DOWNS and PEARSON, Contractors.

SUMMARY of PORTLAND CEMENT, Seven Day Tests, from 1862 to 1863.

NAME OF MANUFACTURER.	Quantity in Bushels.	Average Weight per Bushel.	Number of Tests.	Average Breaking Tests.[1]
		lbs.		lbs.
Mr. Robins	26,438	120·12	430	700·64
Burham Brick and Cement Company (Mr. Webster)	4,720	122·66	30	684·20
Messrs. J. B. White and Brothers	8,054	108·07	140	582·00
Generally	39,212	117·39	600	672·14

[1] Specified standards, 400 lbs. and 500 lbs.

TABLE XII.

METROPOLITAN MAIN DRAINAGE.

SOUTHERN HIGH-LEVEL EXTENSIONS (Dulwich, Brixton, and Denmark-hill Contracts).

Messrs. PEARSON, WEBSTER, and DOWELL, Contractors.

SUMMARY of PORTLAND CEMENT, Seven Day Tests, from 1862 to 1863.

NAME OF MANUFACTURER.	Quantity in Bushels.	Average Weight per Bushel.	Number of Tests.	Average Breaking Tests.[1]
		lbs.		lbs.
Mr. Robins	3,037	114·59	110	674·95
Mr. Hilton	1,200	117·71	60	644·28
Burham Brick and Cement Company (Mr. Webster)	46,206	113·11	610	616·54
Generally	50,443	113·81	780	626·81

[1] Specified standards, 400 lbs. and 500 lbs.

TABLE XIII.

METROPOLITAN MAIN DRAINAGE.

LOW-LEVEL SEWER (Bermondsey Branch).

Messrs. JOHN AIRD and SON, Contractors.

SUMMARY of PORTLAND CEMENT, Seven Day Tests, from 1862 to 1863.

NAME OF MANUFACTURER.	Quantity in Bushels.	Average Weight per Bushel.	Number of Tests.	Average Breaking Tests.[1]
		lbs.		lbs.
Mr. Robins	78,492	119·07	690	688·27

[1] Specified standard, 500 lbs. Sectional area, 2·25 square inches.

TABLE XIV.

METROPOLITAN MAIN DRAINAGE.

SOUTHERN OUTFALL WORKS.

Mr. WILLIAM WEBSTER, Contractor.

SUMMARY of PORTLAND CEMENT, Seven Day Tests, for 1862–1864.

NAME OF MANUFACTURER.	Quantity in Bushels.	Average Weight per Bushel.	Number of Tests.	Average Breaking Tests.[1]
		lbs.		lbs.
Burham Brick and Cement Company (Mr. Webster)	349,620	113·57	2,097	692·99

[1] Specified standard, 500 lbs.

TABLE XV.

METROPOLITAN MAIN DRAINAGE.

SOUTHERN LOW-LEVEL SEWER.

Mr. WILLIAM WEBSTER, Contractor.

SUMMARY of PORTLAND CEMENT, Seven Day Tests, for 1864 and 1865.

NAME OF MANUFACTURER.	Quantity in Bushels.	Average Weight per Bushel.	Number of Tests.	Average Breaking Tests.[1]
		lbs.		lbs.
Burham Brick and Cement Company (Mr. Webster)	220,105	114·15	1,560	669·52
Mr. Hilton	700	114·00	16	598·44
Generally ..	220,805	114·15	1,576	668·79

[1] Specified standard, 500 lbs. Sectional area, 2·25 square inches.

Table XVI.

Table of the Results of 370 Experiments with Portland Cement, weighing 112 lbs. to the Imperial Bushel, gauged neat, and with different proportions of various kinds of Sand, showing the Breaking Weight on a Sectional Area of 2·25 square inches. 1861 and 1862.

Age.	Neat Cement. Breaking Weight in	The same Cement and Thames Sand from Deptford Works in the proportion of					Thames Sand from Southern Outfall Sewer.	Clean Pit Sand.		Inferior, or Loamy Pit Sand.		Last kind of Sand, Washed.	
		1 to 1	1 to 2	1 to 3	1 to 4	1 to 5	1 to 1	1 to 1	1 to 2	1 to 1	1 to 2	1 to 1	1 to 2
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
7 Days ..	558·5	190·7	..	62·0	..	..	213·8	227·8	185·5	166·8	..	224·9	..
28 ditto ..	784·5	373·5	225·7	108·0	90·5	43·0	418·0	423·1	..	376·9	251·5	364·9	330·0
3 Months ..	..	..	..	..	..	116·0	..	..	..	..	..	..	..
6 ditto ..	960·8	603·2	395·7	308·1	149·0	122·5	614·5	625·9	..	..	..	..	..
9 ditto ..	..	..	..	..	..	..	..	..	..	..	..	..	..
12 ditto ..	1009·8	724·0	483·4	371·1	198·2	204·4	757·9	815·4	..	..	..	..	..

TABLE XVII.

TABLE of the Results of 960 Experiments with Portland Cement, weighing 112 lbs. to the Imperial Bushel, gauged neat, and with different proportions of various kinds of Sand, showing the Breaking Weight on a Sectional Area of 2·25 square inches. 1862 and 1863.

AGE AND TIME OF IMMERSION IN WATER.	Cement Neat.	Clean Thames Sand.					Clean Pit Sand.					Loamy Pit Sand.				
		1 to 1	1 to 2	1 to 3	1 to 4	1 to 5	1 to 1	1 to 2	1 to 3	1 to 4	1 to 5	1 to 1	1 to 2	1 to 3	1 to 4	1 to 5
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1 Week	445·0	97·0	52·5	27·0	..	..	152·0	64·5	44·5	22·0	..	114·2	53·0	21·0	..	..
1 Month	679·9	309·3	123·5	58·0	32·5	21·0	326·5	166·5	91·5	71·5	49·0	274·7	130·5	68·0	60·5	31·5
3 Months	877·9	367·0	254·5	135·5	109·0	88·5	549·6	451·9	305·3	153·0	123·5	448·3	354·0	149·0	118·5	78·5
6 ditto	978·7	546·8	425·1	232·4	157·0	95·5	639·2	497·9	304·0	275·6	218·8	586·5	415·6	274·2	225·5	141·0
9 ditto	995·9	607·8	431·5	..	..	..	718·7	594·4	383·6	..	..	600·1	516·8	321·3	226·7	154·3
12 ditto	1075·7	700·3	458·5	320·6	221·6	122·3	795·9	607·5	424·4	317·6	215·6	645·5	533·2	358·4	244·4	166·2

Table XVIII.

Table of the Results of 160 Experiments with Portland Cement, weighing 123 lbs. to the Imperial Bushel, gauged neat, and with an equal proportion of clean Thames Sand, showing the Breaking Weight on a Sectional Area of 2·25 square inches.

These form the first portion of a Series intended to extend over 10 years. The whole of these Specimens were kept in Water from the time of their being made till the time of testing, 1863 and 1866.

Age.	Neat Cement.	1 of Cement to 1 of Sand.
	Average Breaking Test of 10 Experiments.	Average Breaking Test of 10 Experiments.
	lbs.	lbs.
7 Days	817·1	353·2
1 Month	935·8	452·5
3 Months	1055·9	547·5
6 ditto	1176·6	640·3
9 ditto	1219·5	692·4
12 ditto	1229·7	716·6
2 Years	1324·9	790·3
3 ditto	1314·4	784·7

Table XIX.

Table of the Results of 225 Experiments with Portland Cement, weighing 100 lbs. to the Imperial Bushel, gauged neat, and kept—1st, in Water in Testing-house; 2nd, out of Water in Testing-house; and 3rd, out of Water on Roof of Testing-house, exposed to the action of the Weather. August, 1863, to September, 1864.

Age.	Average Breaking Tests of Five Experiments.[1]		
	First.	Second.	Third.
	lbs.	lbs.	lbs.
7 Days	767·6	511·2	522·8
14 ditto	810·6	558·4	627·8
21 ditto	812·4	698·0	708·2
28 ditto	886·4	705·6	636·8
2 Months	881·0	877·0	594·0
3 ditto	952·0	612·8	671·0
4 ditto	968·6	774·6	814·8
5 ditto	993·0	786·6	783·2
6 ditto	1033·4	761·4	783·4
7 ditto	986·6	756·0	901·0
8 ditto	941·0	878·0	814·8
9 ditto	1048·6	845·8	714·0
10 ditto	1037·0	994·0	786·6
11 ditto	1039·4	909·6	876·0
12 ditto	1099·0	827·4	719·6
Total	14256·6	11496·4	10954·0

[1] Sectional area, 2·25 square inches.

Table XX.

Table of the Results of 33 Experiments with Portland Cement, weighing 117 lbs. to the Imperial Bushel, mixed with Fresh and Salt Water from Sheerness. 1863 and 1864.

Sectional area, 2·25 square inches.

Age of Specimens immersed in Water.	Fresh Water. Average Breaking Tests.	Salt Water. Average Breaking Tests.
	lbs.	lbs.
7 Days	738·2	891·00
14 ditto	..	938·66
21 ditto	..	973·50
28 ditto	..	940·40

Table XXI.

Table of the Results of 151 Experiments with Portland Cement, weighing 121 lbs. to the Imperial Bushel, gauged with Fresh and Salt Water. 1864.

Sectional area, 2·25 square inches.

Age of Specimens immersed in Water.	Fresh Water. Average Breaking Tests.	Salt Water. Average Breaking Tests.
	lbs.	lbs.
7 Days	922·0	942·86
14 ditto	1062·6	1056·60
21 ditto	1138·5	1147·70
28 ditto	1123·9	1203·30
2 Months	1175·5	1341·00
3 ditto	1256·9	1368·60
4 ditto	1320·7	1464·00
5 ditto	1327·16	1353·00
Total	9327·26	9877·06

Table XXII.

Table of the Results of 5 Experiments with Roman Cement, mixed neat, and immersed in water for seven days. February, 1859.

Manufacturer.	Number of Specimens.	Weight per Bushel.	Breaking Tests. Sectional area, 2·25 square inches.		
			Minimum.	Maximum.	Average.
		lbs.	lbs.	lbs.	lbs.
Mr. Oldham	2	82·0	271	275	273·0
Mr. E. Cleaver ..	3	79·0	131	138	133·3
Average	5	80·5	201	206·5	189·2

Table XXIII.

Table of the Results of 60 Experiments with Roman Cement, weighing 82 lbs. to the Imperial Bushel, gauged neat, and immersed in water, showing the Breaking Weight on a Sectional Area of 2·25 square inches. 1862 and 1863.

Age.	Roman Cement. Average Breaking Tests of 10 Experiments.
	lbs.
7 Days	77·5
28 ditto	94·5
3 Months	114·5
6 ditto	90·5
9 ditto	85·5
12 ditto	104·3

TABLE XXIV.

TABLE of the Results of 110 Experiments with Roman Cement and Sand. Manufactured by Messrs. COLES, SHADBOLT, & Co. March, 1864.

AGE AND TIME IMMERSED IN WATER.	Neat Cement.			1 Cement to 1 Sand.			1 Cement to 2 Sand.			1 Cement to 3 Sand.			REMARKS.
	Minimum Breaking Test.	Maximum Breaking Test.	Average Breaking Test.	Min. Breaking Test.	Max. Breaking Test.	Average Breaking Test.	Min. Breaking Test.	Max. Breaking Test.	Average Breaking Test.	Min. Breaking Test.	Max. Breaking Test.	Average Breaking Test.	
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	
7 Days	180[1]	213[1]	201·83[1]	60	110	79	..	..	..	..	..	..	[1] Four of these would not bear the minimum strain.
14 ditto	130	215	168·00	..	..	..	10	35	18·5				
21 ditto	200[2]	253[2]	221·14[2]	..	..	..	..	..	..	10	45	17·5	[2] Three of these would not bear the minimum strain.
1 Month	173[3]	283[3]	243·33[3]	..	..	..	..	..	..	..	..	..	[3] One of these would not bear the minimum strain.
3 Months	238	400	329·60										
6 ditto	252	408	376·80										
9 ditto	78	306	167·80										
12 ditto	137	428	323·80										

TABLE XXV.

TABLE of the Results of 90 Experiments with Roman Cement and Sand. Manufactured by Messrs. J. B. WHITE and BROTHERS. March, 1864. Sectional area, 2·25 square inches.

AGE AND TIME IMMERSED IN WATER.	Neat Cement.			1 of Cement to 1 Sand.		
	Minimum Breaking Test.	Maximum Breaking Test.	Average Breaking Test.	Minimum Breaking Test.	Maximum Breaking Test.	Average Breaking Test.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
7 Days	170	240	202·0	15	45	26·5
14 ditto	160	190	173·0	..	..	..
21 ditto	170	205	186·5	..	..	..
1 Month	246	291	260·3	..	..	..
3 Months	307	344	322·5	..	..	..
6 ditto	442	502	472·7	..	..	..
9 ditto	313	520	471·1	..	..	..
12 ditto	596	680	643·1	..	..	..

Table XXVI.

Table of the Results of 250 Experiments with Roman Cement and Sand. Manufactured by Mr. James R. Blashfield. March, 1864. Sectional area, 2·25 square inches.

Age and Time immersed in Water.	Neat Cement.			1 to 1 Sand.			1 to 2 Sand.			1 to 3 Sand.			1 to 4 Sand.			1 to 5 Sand.		
	Min. Breaking Test.	Max. Breaking Test.	Average Breaking Test.	Min. Breaking Test.	Max. Breaking Test.	Average Breaking Test.	Min. Breaking Test.	Max. Breaking Test.	Average Breaking Test.	Min. Breaking Test.	Max. Breaking Test.	Average Breaking Test.	Min. Breaking Test.	Max. Breaking Test.	Average Breaking Test.	Min. Breaking Test.	Max. Breaking Test.	Average Breaking Test.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
7 Days	95	150	120·5	35	75	47·5	5[1]	10[1]	7·0[1]	10[2]	10[2]	10·0[2]	10[3]	10[3]	10[3]			
14 ditto	145	209	169·9	53	79	65·6	22	57	42·8	8[4]	30[4]	19·2[4]				[5]	[5]	[5]
21 ditto	128	171	155·2	54	89	74·2	37	56	45·9	8	25	17·4	[5]	[5]	[5]			
1 Month ..	343	378	358·2	75	91	81·2	8	54	41·9	[5]	[5]	[5]						
3 Months ..	160	274	220·4	32	160	121·9	72[6]	126[6]	91·75[6]				40[7]	54[7]	45·5	29[8]	48[8]	37·71[8]
6 ditto	227	300	252·5	296	337	314·3	..	..	..	..	..	..	..	..	..	..	..	..
9 ditto	169	300	251·5	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
12 ditto	216	300	268·5	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

[1] Five of these would not bear the minimum strain. [2] Eight ditto. [3] Eight ditto. [4] Five ditto.
[5] Five ditto. [6] Two ditto. [7] Six ditto. [8] Three ditto.

TABLE XXVII.

TABLE of the Results of 170 Experiments with Roman Cement and Sand. Manufactured by Messrs. LARK and PARROCK. March, 1864. Sectional area, 2·25 square inches.

AGE AND TIME IMMERSED IN WATER.	Neat Cement.			1 to 1 Sand.			1 to 2 Sand.			1 to 3 Sand.			1 to 4 Sand.			1 to 5 Sand.		
	Min. Breaking Test.	Max. Breaking Test.	Average Breaking Test.	Min. Breaking Test.	Max. Breaking Test.	Average Breaking Test.	Min. Breaking Test.	Max. Breaking Test.	Average Breaking Test.	Min. Breaking Test.	Max. Breaking Test.	Average Breaking Test.	Min. Breaking Test.	Max. Breaking Test.	Average Breaking Test.	Min. Breaking Test.	Max. Breaking Test.	Average Breaking Test.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
7 days	110	160	133·0	47	90	78·0	24	43	30·6	[1]	[1]	[1]						
14 ditto	115	160	136·0	70	96	83·0	8	70	35·1	13	32	25·4	[1]	[1]	[1]	[1]	[1]	[1]
21 ditto	170	220	180·6	84	134	110·6	40	63	52·5	3[2]	6[2]	4·25[2]						
1 Month ..	183	251	216·5	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
3 Months ..	257	334	302·7	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
6 ditto	414	462	438·2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
9 ditto	430	515	454·3	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
12 ditto	436	510	477·9	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
24 ditto	444	550	518·0	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

[1] Would not bear the minimum strain.

[2] Six of these would not bear the minimum strain.

Table XXVIII.

Table of the Results of 120 Experiments with Keene's Cement, manufactured by Messrs. J. B. White and Brothers; and Parian Cement, manufactured by Messrs. Francis and Sons.

In Water in Testing-house, and out of Water in Testing-house, September, 1864.

Sectional area, 2·25 square inches.

Age and Time immersed in Water.	Keene's Cement.		Parian Cement.	
	In Water.	Out of Water.	In Water.	Out of Water.
	Average Breaking Test.	Average Breaking Test.	Average Breaking Test.	Average Breaking Test.
	lbs.	lbs.	lbs.	lbs.
7 Days	543·9	546·0	595·1	642·3
14 ditto	486·9	585·8	600·8	671·2
21 ditto	503·0	579·4	543·4	696·6
1 Month	490·2	584·2	544·3	746·7
2 Months	454·7	648·4	500·7	725·6
3 ditto	508·8	720·5	521·1	853·7

Table XXIX.

Table of the Results of 110 Experiments with Medina Cement and Sand. Manufactured by Messrs. Francis Brothers, 1864.

Sectional area, 2·25 square inches.

Age and Time immersed in Water.	Neat Cement.			1 Cement to 1 Sand.		
	Minimum Breaking Test.	Maximum Breaking Test.	Average Breaking Test.	Minimum Breaking Test.	Maximum Breaking Test.	Average Breaking Test.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
7 Days	83	100	92·1	..	..	..
ditto (2nd Series)	195	235	211·0	41	63	49
14 Days	238	335	303·4	..	..	..
21 ditto	274	332	298·0	..	..	..
1 Month	210	346	306·0	..	..	..
3 Months	420	468	448·8	..	..	..
6 ditto	376	438	412·4	..	..	..
9 ditto	438	507	457·2	..	..	..
12 ditto	456	527	476·9	..	..	..
2 Years	235	328	276	..	..	..

TABLE XXX.

TABLE of 178 Experiments on the Compression of Portland Cement Bricks.
Size 9 × 4·25 × 2·75 = 105·18 cubic inches; and exposed to Pressure 9 × 4·25 = 38·25 square inches. 1860 and 1861.

DESCRIPTION OF BRICKS.	Pressure when Specimen first showed signs of giving.			Pressure when Specimen finally crushed.			REMARKS.
	Minimum in Tons.	Maximum in Tons.	Average in Tons.	Minimum in Tons.	Maximum in Tons.	Average in Tons.	
Neat Portland Cement	26·0	56·0	42·00	56·1	77·8	64·81	Made 3 Months.
1 Portland Cement to 1 Pit Sand ..	14·0	35·0	29·24	34·6	46·9	42·53	
ditto 2 ditto	18·0	30·0	25·50	28·5	39·6	34·22	
ditto 3 ditto	13·5	24·5	19·99	20·4	27·0	24·52	
ditto 4 ditto	12·5	24·0	20·62	20·0	25·8	22·73	
ditto 5 ditto	0·9	16·0	10·29	11·7	19·2	16·37	
Neat Portland Cement	32·0	82·1	58·35	79·1	100·0	92·01	Made 6 Months.
1 Portland Cement to 1 Sand	16·2	55·1	32·82	54·2	66·1	59·39	
ditto 2 ditto	10·2	49·4	24·80	35·0	57·3	47·00	
ditto 3 ditto	10·1	40·0	19·42	32·1	43·1	36·81	
ditto 4 ditto	8·0	14·2	10·13	27·3	44·2	30·68	
ditto 5 ditto	8·0	19·0	11·91	21·8	31·8	26·29	
Neat Portland Cement	5·0	67·0	37·00	92·8	110·2	102·19	Made 9 Months.
1 Portland Cement to 1 Pit Sand ..	44·4	76·1	64·40	65·1	85·3	77·88	
ditto 2 ditto	35·0	65·1	51·13	47·4	73·1	62·28	
ditto 3 ditto	16·2	41·0	33·25	34·1	46·3	40·87	
ditto 4 ditto	12·1	33·2	25·38	32·0	42·0	37·71	
ditto 5 ditto	10·0	26·2	19·40	24·0	38·2	28·66	

Table XXXI.

Table of 173 Experiments on the Compression of Bricks. 1863.

Manufacturer.	Description of Bricks.	No. of Specimens.	Weight of Specimens.	Contents of Specimens. Cubical Contents.	Area exposed to pressure.	Dimensions of Specimens. Lgth.	Bdth.	Thickness.	Pressure when Specimen first showed signs of giving. Min.	Max.	Average.	Pressure when Specimen finally crushed. Min.	Max.	Average.	Remarks.
			lbs.	inches.	inches.	in.	in.	in.	tons.	tons.	tons.	tons.	tons.	tons.	
Mr. Harrison..	.. ..	5	..	103·73	37·72	8·88	4·25	2·75	13·10	28·20	15·900	62·0	83·2	68·15	Used on Bermondsey Branch.
	Gault Bricks ..	5	..	101·26	37·18	8·75	..	..	3·2	39·00	13·380	28·0	46·3	37·90	ditto.
	ditto	5							6·5	20·2	12·120	29·2	36·0	32·38	ditto; Frogs filled with Portland Cement.
Messrs. Allan, Sudbury.	Brimstone, Suffolks	4	..	108·94	41·58	9·00	4·62	2·62	2·0	6·4	4·475	23·2	40·0	31·75	Deptford Pumping Station.
ditto	ditto	4	..	..	..	..	..	..	4·4	33·6	17·100	40·2	54·0	48·45	ditto.
ditto	ditto	10	6·8	111·10	41·34	9·06	4·56	2·69	1·0	8·0	5·100	25·0	37·0	31·00	Used on the Southern Outfall Contract.
ditto	Best Whites ..	10	6·6	89·99	41·90	9·19	..	2·62	1·0	9·0	5·100	16·0	27·0	19·60	ditto.
ditto	No. 3 Suffolks ..	10	6·4	112·64	41·91	9·06	4·63	2·69	1·0	8·0	4·000	15·0	24·0	19·10	ditto.
Mr. Salters, Chilton ..	Best Whites ..	10	6·3	104·44	40·76	9·19	4·38	2·56	2·0	10·0	5·300	19·0	36·0	25·90	ditto.
ditto	No. 2 Suffolks ..	10	7·1	109·26	41·62	9·25	4·50	2·63	1·0	12·0	6·600	24·0	41·0	33·20	ditto.
Mr. Webster, Burham .	Gault Wire Cut No. 2 ..	10	5·4	80·56	34·50	8·63	4·00	2·63	1·0	10·0	6·400	10·0	50·0	32·90	ditto.
ditto	ditto Pressed No. 1 ..	10	6·1	98·47	36·64	8·75	4·19	2·69	1·0	18·0	7·400	31·0	45·0	36·80	ditto.
Mr. Betts, Aylesford ..	ditto	10	6·4	99·42	36·11	8·63	..	2·75	2·0	14·0	7·300	24·0	69·0	32·40	ditto.
Mr. Stares, Fareham ..	Best Reds	10	6·3	94·82	36·13	8·50	4·25	2·62	1·0	15·0	8·420	19·0	37·0	26·10	ditto.
ditto	Best Rubbers ..	10	8·8	145·83	49·64	10·19	4·88	2·94	1·0	3·0	1·400	11·0	21·0	15·70	ditto.
Mr. Pearson, Stourbridge	Best Firebricks .	10	7·3	101·62	39·66	8·94	4·44	2·56	3·0	25·0	15·800	56·0	71·0	62·80	ditto.
Mr. Ambrose, Colchester	No. 2 Salmon ..	10	6·5	97·53	41·34	9·19	4·50	2·63	1·0	16·0	8·900	26·0	45·0	36·70	ditto.
Messrs. Knight, Woodbridge	No. 2 Suffolks ..	10	6·1	99·45	38·81	9·00	4·31	2·56	5·0	14·0	8·800	33·0	42·0	37·30	ditto.
Mr. Smeed, Sittingbourne	Good Stocks ..	10	5·3	90·88	36·35	8·81	4·13	2·50	1·0	11·0	5·700	26·0	46·0	33·90	ditto.
Mr. Gilbert, Tipton ..	Best Blue	10	8·0	94·33	37·73	8·75	4·31	2·50	5·0	75·0	21·600	52·0	*100·0	*95·20	ditto.

Those marked * withstood the utmost pressure of the Press.

Table XXXII.

Table of 82 Experiments on the Compression of Bricks. 1859 and 1860.

Manufacturer.	Description of Bricks.	No. of Specimens.	Contents of Specimens.		Dimensions of Specimens.			Pressure when Specimen first showed signs of giving.			Pressure when Specimen finally crushed.			Remarks.
			Cubical Contents.	Area exposed to Pressure.	Lngth.	Brdth.	Thickness.	Minimum.	Maximum.	Average.	Minimum.	Maximum.	Average.	
			in.	in.	in.	in.	in.	tons.	tons.	tons.	tons.	tons.	tons.	
Messrs. Platt Bros..	.. .. ..	1	113·66	39·33	9·0	4·37	2·89	5·0	5·0	5·00	40·0	40·0	40·00	From Hartford Iron Works, Oldham.
ditto	.. .. ..	1						40·0	40·0	40·00	45·2	45·2	45·20	ditto; Frogs filled with dry Cement.
Mr. W. Webster, Burham ..	Gault Bricks	5	111·37	40·50	..	4·5	2·75	5·0	11·0	7·46	14·0	20·1	17·26	Used on Low Level, Bermondsey Branch.
ditto	ditto	5						13·3	19·0	16·46	27·2	33·4	30·48	ditto; the Frogs of these Bricks were filled with Cement.
ditto	No. 1 Gault pressed Bricks.. ..	10	105·30	..	..	..	2·60	4·6	15·0	9·10	36·0	55·6	48·00	Used for face-work, Church Street, Deptford; Frogs filled with Cement.
ditto	ditto	10						5·0	18·0	8·76	28·2	42·6	32·70	Used for face-work, Church Street.
ditto	Wire Cut	10	101·25	..	..	..	2·50	1·0	36·2	10·42	46·0	73·8	60·78	Used at Deptford Pumping Station.
ditto	Shippers' Stocks ..	10						1·5	13·2	4·88	25·2	37·4	32·72	ditto.
ditto	ditto	10						1·0	27·2	8·08	37·8	55·6	39·63	ditto; and Frogs filled with Cement.
Mr. Betts, Aylesford	Gault pressed Bricks	10	91·13	..	..	..	2·25	3·5	11·6	8·46	25·6	50·4	35·22	Used on the Bermondsey Branch.
ditto	ditto	10						3·1	17·4	10·77	27·6	48·0	36·64	ditto; Frogs filled with Cement.

TABLE XXXIII.

ABSTRACT of 38 Experiments on the Strength of various kinds of Bricks, &c. 1859 and 1860.

DATE.	Name of Maker.	Description of Bricks.	No. of Experiments.	Length.	Breadth.	Thickness.	Superficial Area.	Weight of Brick.	Minimum.	Maximum.	Total crushing Power. Average.	Crushing Power per Square Inch.
				inches.	inches.	inches.	inches.	lbs. oz.	tons.	tons.	tons.	lbs.
1859. May 28th	Mr. Gilbert	Blue Brick	1	9·00	3·1	4·2	27·90	..	..	..	50·00	4,014
„	„ „	„	1	8·75	6·0	4·2	52·50	..	..	..	75·00	3,200
„	„ Cliff..	Fireclay Brick	1	8·50	4·1	2·5	34·85	..	..	..	{65·62 {37·50	4,218 2,401
„	„ Platt	Red, Machine Brick ..	1	9·00	4·20	2·8	37·80	..	..	..	28·12	1,667
„	„ „	„ „ ..	1	9·10	2·85	4·1	25·93	..	..	..	18·75	1,619
Nov. 8th	„ Aylesford ..	.. ..	5	..	..	..	..	..	35·0	53	43·00	..
„	„ Eastwoods ..	.. ..	5	9·00	4·0	3·0	36·00	..	13·5	27	18·90	1,176
Aug. 9th	„ Taylor	Blue Brick	5	9·00	4·32	3·0	38·88	..	63·0	90	50·60	2,915
„	„ Gilbert	„	2	8·60	4·08	2·88	35·09	..	72·0	78	75·00	4,759
„	„ Cliff, Wortley Works, Leeds	„	1	8·52	4·08	2·76	34·76	..	72·0	72	72·00	4,639
1860. March	„ Helling	Clay Bricks	3	8·75	4·30	3·10	37·63	7·9	24·0	27	26·00	1,574
„	„	Out of Norwood Tunnel,	1	9·30	4·60	3·0	42·78	8·15	36·0	36	36·00	1,885
„	„	pressed Bricks	2	8·75	4·30	3·1	37·63	8·4	45·0	56	50·50	3,033
„	„	„ „	2	8·75	4·5	3·1	39·38	7·11	27·0	30	28·50	1,618
„	„	„ „	2	9·25	4·3	2·9	39·78	8·8	34·0	35	34·50	1,942
„	„	„ „	1	8·90	4·3	3·0	38·27	7·2	10·0	10	10·00	585
„	„	„ „	1	8·60	4·25	3·0	36·55	8·4	27·0	27	27·00	1,654
„	„	„ „	3	8·90	4·25	2·6	37·82	4·15	37·0	52	42·00	2,487

TABLE XXXIV.

TEN EXPERIMENTS MADE AT CROSSNESS PUMPING STATION.

GISBORNE'S EXBURY BRICKS—No. 1. January 12th, 1864.

Description of Brick.	Number of Specimens.	Size.			Cracked.			Crushed.			Area.	Cubical Contents.	Pressure per Square Inch.	Pressure per Cubic Inch.
		Length.	Breadth.	Depth.	Min.	Max.	Average	Min.	Max.	Average				
		inches.	inches.	inches.	tons.	tons.	tons.	tons.	tons.	tons.	inches.	inches.	lbs.	lbs.
No. 1 Exbury's Best	4	8·875	4·25	2·75	20	23	21·00	24	33	28·5	37·73	85·75	1,692	743
Second Quality ..	2	..	..	..	22	22	22·00	28	30	29·0	..	..	1,722	757
Third ditto	3	8·500	4·125	2·625	4	16	11·33	27	30	29·0	35·06	92·04	1·853	706
Unburnt Brick ..	1	8·875	4·375	2·875	1	1	1·00	9	9	9·0	38·83	111·63	0·519	180

TABLE XXXV.

TABLE of 21 Experiments on small Blocks of Stone, of the dimensions of an average Brick, with Frogs sunk therein. 1864.

Description of Stone Experimented on.	Weight when Cracking first took place.			Weight when Stone was Crushed.			Weight.	Size in Inches.			Area.	Cubical Contents	Crushing Power per Sq. Inch.
	Min.	Max.	Average	Min.	Max.	Average							
	tons.	tons.	tons.	tons.	tons.	tons.	lbs.				inches.	inches.	lbs.
Portland Stone on the Bed	10	12	11·00	46	48	47·00	9						2,631
Portland against the Bed	7	10	8·33	38	38	42·66	10						2,393
Bramley Fall on the Bed	8	25	14·33	84	98	91·33	..	8·875	0·45	2·75	39·94	109·83	5,122
Bramley Fall against the Bed	9	12	9·66	47	57	52·66	..						2,953
Yorkshire Landing on the Bed	20	28	2·33	88[1]	100[1]	96·00[1]	..						5,384
Yorkshire Landing against the Bed	17	28	21·66	100[2]	100[2]	100·00[2]	..	8·75	4·375	2·75	38·28	105·27	5,852

[1] These specimens were not crushed, 100 tons being the maximum pressure which the Press was capable of giving.
[2] Just on the point of crushing.

Table XXXVI.

Quantities used in making Brickwork Blocks, in Compo composed of Portland Cement and River Sand in equal proportions, each Block being a 3 feet cube = 1 cubic yard. February, 1865. Number of Bricks in each Block, 384.

Materials.	No. 1 Block. Gault Bricks with Frogs. Average, 8·75×4·1 ×2·75=98·6562.		No. 2 Block. Gault Bricks, Wire Cut, no Frogs. Average size, 9·08 ×4·14×2·75=105·08.		No. 3 Block. Sand Stocks. Average size, 9·08 ×4·21×2·70 =105·7573.	
	bushels.	cubic feet.	bushels.	cubic feet.	bushels.	cubic feet.
Cement weighing 112 lbs. per bushel	3·615	4·6406	3·29	4·2187	3·29	4·2187
Sand	3·615	4·6406	3·29	4·2187	3·29	4·2187
Bricks	17·090	21·9236	17·98	23·0786	18·29	23·4780
Totals	24·320	31·2048	24·56	31·5160	24·87	31·9154

Table XXXVII.

Showing Two Series of Experiments as to the Quantities of Portland Cement, Sand, and Water used in making One Cubic Yard of Compo, or Cement Mortar.

P.C. Sand.	First Series.	Bushels.	Second Series.	Bushels.
1 to 1	Cement	12¼	Cement	13
	Sand	12¼	Sand	13
		24½		26
	56 Gallons of Water.		48 Gallons of Water.	
1 to 2	Cement	8¼	Cement	8½
	Sand	16½	Sand	17
		24¾		25½
	44 Gallons of Water.		36 Gallons of Water.	
1 to 3	Cement	6½	Cement	6¼
	Sand	19½	Sand	18¾
		26		25
	46 Gallons of Water.		28½ Gallons of Water.	
1 to 4	Cement	5¼	Cement	5
	Sand	21	Sand	20
		26¼		25
	47 Gallons of Water.		38 Gallons of Water.	
1 to 5	Cement	4¼	Cement	4⅛
	Sand	21¼	Sand	20⅝
		25½		24¾
	51 Gallons of Water.		34 Gallons of Water.	

Table XXXVIII.

Eighty Experiments with Neat Portland Cement immersed in Water immediately on Setting, intended to illustrate the Increase of Strength from One to Fourteen Days. Weight, 104 lbs. per Bushel.

The Series for each Day consisted of Ten Samples out of a Quantity selected from various bags.

Age of Specimens in Days.	Average Breaking Strain on 2·25 Square Inches.
	lbs.
1	133·
2	417·7
3	500·8
4	540·4
5	586·0
6	665·9
7	705·5
14	826·8

Table XXXIX.

Showing Tensile Strains of Cements of different Specific Gravities at different Periods. Sectional area, 2·25 square inches.

No. of Table.	Weight per Bushel.	1 Week.	1 Month or 4 Weeks.	1 Year.
	lbs.			
19	109	767·6	886·4	1099·0
16	112	558·5	784·5	1009·8
17	112	445·0	679·9	1075·7
18	123	817·0	935·8	1229·7

TABLE XL.

SOUTHERN OUTFALL WORKS, CROSSNESS.

SUMMARY of Portland Cement Tests, from 1862 to 1866, showing generally increase of Strength with increased Specific Gravity.

Number of Bushels.	Average Weight per Bushel.	Tensile Strain on area = 2·25 Square Inches.
	lbs.	lbs.
1,800	106	472·6
5,800	107	592·3
26,166	108	650·1
37,036	109	646·6
20,820	110	708·3
6,900	111	693·8
13,812	112	687·5
10,610	113	701·5
24,224	114	699·7
16,240	115	705·5
27,400	116	768·3
26,800	117	718·4
23,306	118	644·1
12,500	119	777·9
18,530	120	732·3
15,144	121	705·6
5,000	122	716·6
5,428	123	673·6
13,400	124	819·9
5,400	125	816·2
1,800	126	657·2
1,800	127	864·6
3,600	128	916·6
1,820	129	920·2
1,800	130	913·9
327,136	..	550·6

TABLE XLI.

SOUTHERN OUTFALL WORKS, CROSSNESS, JANUARY, 1866.

FOUR HUNDRED AND EIGHTY EXPERIMENTS with Neat Portland Cement, showing Strength after setting from One to Seven Days.

DAYS IMMERSED IN WATER.	Messrs. White & Co., Blackfriars.		Burham Company, Crossness.		Burham Company, Specimens.		Messrs. Francis, Nine Elms.		Burham Company, Woolwich.		Messrs. Weeks, Plumstead.		Burham Company, Crossness.	
	Weight 98 lbs.		Weight 104 lbs.		Weight 112 lbs.		Weight 115 lbs.		Weight 116 lbs.		Weight 118 lbs.		Weight 118 lbs.	
	Tensile Strain on 2·25 Sectional Area.	Tensile Strain per Square Inch.	Tensile Strain on 2·25 Sectional Area.	Tensile Strain per Square Inch.	Tensile Strain on 2·25 Sectional Area.	Tensile Strain per Square Inch.	Tensile Strain on 2·25 Sectional Area.	Tensile Strain per Square Inch.	Tensile Strain on 2·25 Sectional Area.	Tensile Strain per Square Inch.	Tensile Strain on 2·25 Sectional Area.	Tensile Strain per Square Inch.	Tensile Strain on 2·25 Sectional Area.	Tensile Strain per Square Inch.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1	195	87	116	52	202	90	170	76	125	56	171	76	134	60
2	295	131	279	124	391	174	450	200	395	176	486	216	417	185
3	347	154	356	158	541	240	594	264	428	190	607	270	501	223
4	418	186	505	224	590	262	824	366	499	222	708	315	540	240
5	462	205	471	209	768	341	811	360	575	256	777	345	586	260
6	481	214	519	231	..	..	791	352	599	266	681	303	666	296
7	475	211	575	256	740	329	947	421	614	273	650	289	705	313

TABLE XLII.

SOUTHERN OUTFALL WORKS, CROSSNESS.

EXPERIMENTS in Crushing Blocks of Granite, York, Portland, and Bramley Fall Stones; and Neat Portland, Roman, Parian, Medina, and Keene's Cements.

Size of Blocks, 3 in. × 3 in. × $1\frac{1}{2}$ in. Crushed by Hydraulic Press, January 8th, 1866.

1	2	3	4	5	6	7	8	9	10	11	12	
No. of Specimens.	Description of Blocks.	Age.			Area exposed to Compression.	Compression.			Pressure borne per Square Inch.		Tensile Strain per Square Inch.	Remarks.
		In Water.	Out of Water.	Total.		Minimum.	Maximum.	Average.	On Edge, Area 4·5.	Flat, Area 9·0.		
		days.	days.	days.	inches.	tons.	tons.	tons.	lbs.	lbs.	lbs.	
5	Granite Stone ..	..	..	..	4·5	11·4	19·4	15·80	7,865	..	..	
5	ditto ..	..	..	..	9·0	25·4	47·4	38·12	..	9,488	..	
10	York Stone ..	..	..	..	4·5	9·3	17·6	12·81	6,376	..	..	
10	ditto ..	..	..	..	9·0	37·8	47·4	40·52	..	10,085	..	Two pieces of Portland stone cut to shape and size of the cement moulds = $1\frac{1}{2}$ inch × $1\frac{1}{2}$ inch = 2·25 square inches.
10	Portland Stone ..	..	..	..	4·5	3·1	8·7	5·79	2,882	..	..	
10	ditto ..	..	..	..	9·0	13·8	22·2	18·44	..	4,589	..	
2	ditto ..	..	..	..	..	..	..	..	..	..	296	
10	Bramley Fall Stone	..	..	..	4·5	3·6	6·2	4·89	2,434	..	..	
10	ditto ..	..	..	..	9·0	17·6	28·6	21·18	..	5,272	..	
10	Portland Cement	7	1,049	1,056	4·5	8·4	15·0	10·62	5,287	..	318	
10	ditto ..	7	776	783	4·5	7·0	9·8	7·89	3,928	..	218	
10	ditto ..	7	619	626	4·5	10·1	18·0	13·51	6,725	..	413	The tensile strain is taken on Specimens of the age shown in Columns 3 and 4. The Portland Cement was the same as used on the Southern Outfall Works, Crossness.
10	ditto ..	7	333	340	4·5	7·1	15·0	10·93	5,442	..	371	
10	ditto ..	7	364	371	4·5	7·6	9·7	8·72	4,341	..	334	
10	ditto ..	7	1,034	1,041	4·5	7·8	11·0	9·69	4,823	..	317	
10	ditto ..	7	754	761	4·5	7·4	11·0	9·13	4,546	..	331	
10	ditto ..	7	664	671	4·5	6·8	11·2	9·15	4,555	..	322	
10	ditto ..	7	1,042	1,049	9·0	16·8	29·6	24·74	..	6,158	274	
10	ditto ..	7	776	783	9·0	18·8	24·6	21·44	..	5,336	253	
10	ditto ..	7	623	630	9·0	22·3	32·1	27·40	..	6,820	389	
10	ditto ..	7	364	371	9·0	20·6	32·8	23·90	..	5,948	287	
10	ditto ..	7	754	761	9·0	16·4	34·8	22·38	..	5,570	328	
10	ditto ..	7	668	675	9·0	17·8	30·0	22·80	..	5,675	324	
10	ditto ..	7	438	445	9·0	21·0	26·0	22·78	..	5,670	325	

TABLE XLII.—Experiments in Crushing Blocks of Granite, York, Portland, and Bramley Fall Stones, &c.—*continued.*

1	2	3	4	5	6	7	8	9	10	11	12	
No. of Specimens.	Description of Blocks.	Age.			Area exposed to Compression.	Compression.			Pressure borne per Square Inch.		Tensile Strain per Square Inch.	Remarks.
		In Water.	Out of Water.	Total.		Minimum.	Maximum.	Average.	On Edge, Area 4·5.	Flat, Area 9·0.		
		days.	days.	days.	inches.	tons.	tons.	tons.	lbs.	lbs.	lbs.	
5	Roman Cement ..	7	667	674	4·5	3·7	4·8	4·26	2,121	..	88	
4	ditto ..	14	653	667	4·5	3·9	5·0	4·45	2,215	..	81	
2	ditto ..	21	653	674	4·5	5·0	6·0	5·50	2,738	..	83	
2	ditto ..	31	643	674	4·5	3·9	4·5	4·20	2,091	..	113	
2	ditto ..	93	581	674	4·5	4·0	5·7	4·85	2,414	..	147	
2	ditto ..	183	490	673	4·5	5·8	7·5	6·65	3,310	..	207	
2	ditto ..	274	399	673	4·5	7·0	8·9	7·95	3,958	..	208	
2	ditto ..	365	307	672	4·5	8·1	8·6	8·35	4,157	..	296	
5	ditto ..	7	667	674	9·0	8·7	12·0	10·38	..	2,584	92	
3	ditto ..	14	660	674	9·0	8·4	15·4	11·23	..	2,795	73	
9	ditto ..	21	653	674	9·0	8·2	13·6	10·88	..	2,708	84	
4	ditto ..	31	642	673	9·0	8·5	11·2	9·30	..	2,315	114	
2	ditto ..	93	580	673	9·0	10·8	11·4	11·10	..	2,764	145	
2	ditto ..	183	490	673	9·0	16·0	21·6	18·80	..	4,679	202	
2	ditto ..	275	398	673	9·0	19·2	20·8	20·00	..	4,978	218	
2	ditto ..	365	308	673	9·0	16·0	18·6	17·30	..	4,306	296	
2	ditto ..	7	678	685	9·0	8·0	8·8	8·40	..	2,091	179	
2	ditto ..	14	670	684	9·0	6·4	7·4	6·90	..	1,717	71	
2	ditto ..	21	663	684	9·0	9·4	9·5	9·45	..	2,352	187	
2	ditto ..	31	653	684	9·0	12·8	14·8	13·80	..	3,435	192	
2	ditto ..	91	594	685	9·0	9·0	12·6	10·80	..	2,688	159	
2	ditto ..	183	501	684	9·0	13·6	15·2	14·40	..	3,584	179	
3	ditto ..	273	411	684	9·0	13·0	13·4	13·26	..	3,300	118	
2	ditto ..	365	319	684	9·0	21·6	25·2	23·40	..	5,824	134	
2	ditto ..	7	678	685	4·5	3·0	3·7	3·35	1,668	..	180	

TABLE XLII.—Experiments in Crushing Blocks of Granite, York, Portland, and Bramley Fall Stones, &c.—*continued.*

1 No. of Speci-mens.	2 Description of Blocks.	3 Age. In Water.	4 Age. Out of Water.	5 Age. Total.	6 Area exposed to Compres-sion.	7 Compression. Minimum.	8 Compression. Maximum.	9 Compression. Average.	10 Pressure borne per Square Inch. On Edge, Area 4·5.	11 Pressure borne per Square Inch. Flat, Area 9·0.	12 Tensile Strain per Square Inch.	Remarks.
		days.	days.	days.	inches.	tons.	tons.	tons.	lbs.	lbs.	lbs.	
2	Roman Cement ..	14	671	685	4·5	3·1	4·5	3·80	1,892	..	186	
2	ditto ..	21	664	685	4·5	4·1	4·5	4·30	2,140	..	188	
2	ditto ..	31	654	685	4·5	4·6	4·8	4·70	2,340	..	193	
4	ditto ..	91	594	685	4·5	5·0	7·8	5·75	2,862	..	148	
2	ditto ..	183	502	685	4·5	7·7	8·0	7·85	3,908	..	170	
3	ditto ..	273	411	684	4·5	7·4	9·0	8·00	3,982	..	75	
6	ditto ..	365	319	684	4·5	7·3	9·8	8·50	4,231	..	159	
10	Parian Cement ..	61	[1]449	510	4·5	4·5	9·0	6·82	3,395	..	322	[1] Time made, but not put in Water.
10	ditto ..	91	[1]419	510	9·0	16·0	18·6	17·12	..	4,261	379	
2	ditto ..	7	486	493	4·5	4·4	6·0	5·2	2,588	..	263	
2	ditto ..	14	479	493	4·5	3·0	4·4	3·7	1,842	..	261	
2	ditto ..	21	470	491	4·5	3·1	4·1	3·6	1,792	..	249	
2	ditto ..	30	461	491	4·5	4·2	5·6	4·9	2,439	..	245	
2	ditto ..	61	430	491	4·5	2·5	3·9	3·20	1,592	..	213	
2	ditto ..	92	399	491	4·5	4·0	4·4	4·20	2,091	..	240	
2	ditto ..	7	486	493	9·0	15·4	16·8	16·1	..	4,007	254	
2	ditto ..	14	479	493	9·0	15·0	18·4	16·7	..	4,156	265	
2	ditto ..	21	470	491	9·0	13·2	14·2	13·7	..	3,410	236	
2	ditto ..	30	461	491	9·0	12·8	16·0	14·4	..	3,584	231	
2	ditto ..	61	430	491	9·0	11·6	13·6	12·60	..	3,136	231	
2	ditto ..	92	399	491	9·0	14·6	18·6	16·60	..	4,131	236	
3	Medina Cement ..	7	654	661	4·5	4·6	5·7	5·03	2,503	..	89	
3	ditto ..	14	646	660	4·5	4·5	4·9	4·63	2,305	..	132	
3	ditto ..	21	640	661	4·5	4·0	5·5	4·56	2,248	..	132	
3	ditto ..	30	631	661	4·5	4·1	5·2	4·80	2,389	..	123	

TABLE XLII.—Experiments in Crushing Blocks of Granite, York, Portland, and Bramley Fall Stones, &c.—*continued.*

1	2	3	4	5	6	7	8	9	10	11	12	
No. of Specimens.	DESCRIPTION OF BLOCKS.	Age.			Area exposed to Compression.	Compression.			Pressure borne per Square Inch.		Tensile Strain per Square Inch.	REMARKS.
		In Water.	Out of Water.	Total.		Minimum.	Maximum.	Average.	On Edge, Area 4·5.	Flat, Area 9·0.		
		days.	days.	days.	inches.	tons.	tons.	tons.	lbs.	lbs.	lbs.	
2	Medina Cement ..	91	570	661	4·5	5·5	6·4	5·95	2,962	..	193	
2	ditto ..	183	478	661	4·5	7·4	7·5	7·45	3,708	..	185	
2	ditto .	273	388	661	4·5	7·1	8·1	7·60	3,783	..	213	
2	ditto ..	365	296	661	4·5	7·0	7·4	7·20	3,584	..	204	
2	ditto ..	7	653	660	9·0	10·0	10·2	10·10	..	2,514	97	
2	ditto ..	14	646	660	9·0	9·1	10·4	9·75	..	2,427	121	
2	ditto ..	21	638	659	9·0	10·4	10·6	10·50	..	2,613	127	
2	ditto ..	30	630	660	9·0	9·5	10·8	10·15	..	2,526	129	
5	ditto ..	92	568	660	9·0	13·2	14·6	14·24	..	3,544	201	
2	ditto ..	183	477	660	9·0	20·0	22·8	21·40	..	5,326	190	
2	ditto ..	273	387	660	9·0	16·8	17·6	17·20	..	4,281	199	
3	ditto ..	365	295	660	9·0	16·2	22·4	19·86	..	4,943	207	
5	Keene's Cement ..	7	516	523	9·0	12·0	14·4	13·36	..	3,325	247	
5	ditto ..	14	509	523	9·0	9·7	14·4	11·42	..	2,842	218	
5	ditto ..	21	502	523	9·0	9·8	17·0	14·00	..	3,484	222	
5	ditto ..	30	493	523	9·0	11·8	15·6	14·12	..	3,514	216	
5	ditto ..	60	469	529	9·0	11·0	14·0	12·84	..	3,195	202	
5	ditto ..	92	431	523	9·0	11·0	17·0	14·68	..	3,956	224	

Table XLIII.

SOUTHERN OUTFALL WORKS, CROSSNESS.

Experiments with Blocks of various Substances. Crushed January, 1866.

Description.	Date when made.	Dimensions.	Cubical Contents.	Superficial Area exposed to Press.	Crushing Power.	Crushing Power per Square Inch.	Weight of Specimen.	Remarks.
		inches.	inches.	inches.	tons.	lbs.	lbs.	
1 Portland Cement & 6 Thames Ballast ..	March 1865.	12 × 12 × 12	1,728	144	60·0	933	136	The crushing power is taken on first symptoms of failure.
1 ditto ditto ..		12 × 12 × 12	1,728	144	52·4	815		
1 Portland Cement to 8 Thames Ballast[1]		12 × 12 × 12	1,728	144	70·6	1,098		
1 ditto to 6 ditto		12 × 12 × 6	864	144	40·4	628		
1 ditto ditto		12 × 12 × 3	432	144	17·0	264		
1 ditto ditto		12 × 12 × 12	1,728	144	63·0	980	..	Kept in Water.
1 ditto to 8 Thames Ballast ..		12 × 12 × 12	1,728	144	83·2	1,294	..	
1 Blue Lias Lime & 6 Thames Ballast ..		12 × 12 × 12	1,728	144	6·0	93	133	
1 ditto & 6 Bramley Fall Chippings		12 × $7\frac{1}{2}$ × 6	540	90	5·0	124	..	
1 ditto & 6 ditto		12 × 12 × 12	1,728	144	20·4	317	..	
1 Portland Cement and Port Nant Granite Chippings		12 × 12 × 12	1,728	144	58·6	911	..	
1 Block of Brickwork, 1 Cement to 1 Sand	Jan., 1865.	$13\frac{1}{2}$ × 12 × 9	1,458	162	21·6	299		
1 ditto ditto		12 × 18 × 9	1,944	216	20·8	216		
1 ditto ditto		$13\frac{1}{2}$ × 9 × 9	1,094	122	15·2	295		
1 ditto ditto		18 × 9 × 9	1,458	162	16·0	221		
1 Neat Portland Cement	Dec. 22, 1865.	12 × 12 × $12\frac{1}{2}$	1,800	144	*	..	139	* 100 tons would not fracture this Specimen.
1 Block $\frac{1}{2}$ Portland Cement $\frac{1}{2}$ Sand		12 × 12 × $10\frac{3}{8}$	1,494	144	95·0	1,478	115	
1 ditto $\frac{1}{3}$ ditto $\frac{2}{3}$ ditto		12 × 12 × $10\frac{1}{4}$	1,476	144	75·0	1,167	112	
1 ditto $\frac{1}{4}$ ditto $\frac{3}{4}$ ditto		12 × 12 × 11	1,584	144	47·0	731	117	
1 ditto $\frac{1}{5}$ ditto $\frac{4}{5}$ ditto		12 × 12 × $10\frac{1}{8}$	1,458	144	26·0	404	107	
1 ditto $\frac{1}{6}$ ditto $\frac{5}{6}$ ditto		12 × 12 × $10\frac{1}{8}$	1,458	144	23·0	358	107	

[1] The weight of one cubic yard of Portland cement concrete (1 to 8), wet, as put into the work, was $30\frac{1}{2}$ cwt. = 3416 lbs.

CLAUSE AS IN EARLIER SPECIFICATIONS.

21. The whole of the cement to be used in these works and referred to in this specification, is to be Portland cement of the very best quality, ground extremely fine, weighing not less than 110 lbs. to the striked bushel, and capable of maintaining a breaking weight of 400 lbs. seven days after being made in an iron mould, of the form and dimensions shown on Drawing No. 1, and immersed six of these days in water.

CLAUSE AS FIRST AMENDED.

27. The whole of the cement shall be Portland cement of the very best quality, ground extremely fine, weighing not less than 110 lbs. to the striked bushel, and capable of maintaining a breaking weight of 500 lbs. seven days after being made in an iron mould, of the form and dimensions shown on Drawing No. 1, and immersed in water during the interval of seven days. The Contractor shall at all times keep in store upon the works a supply of cement equal to at least fourteen days' requirements; and with each delivery of cement shall send to the Clerk of Works a memorandum of the number of bushels sent in, and the name of the manufacturer.

CLAUSE AS LAST AMENDED.

25. The whole of the cement shall be Portland cement of the very best quality, ground extremely fine, weighing not less than 112 lbs. to the striked bushel, and capable of maintaining a breaking weight of 250 lbs. per square inch seven days after being made in a brass mould, and immersed in water during the interval of seven days. The Contractor shall at all times keep in store upon the works a supply of cement equal to at least fourteen days' requirements; and with each delivery of cement shall send to the Clerk of Works a memorandum of the number of bushels sent in, and the name of the manufacturer.

METROPOLITAN MAIN DRAINAGE.

Register of Portland Cement.

186 . *Manufactured by*

Delivered.	Quantity in Bushels	Weight per Bushel.	When Moulded.	When Tested.	Days in Moulds.	Broke at lbs.	No. of Test.	Remarks.
1.	2.	3.	4.	5.	6.	7.	8.	

Mr. G. W. Hemans thought the Paper just read formed the best record of experiments on cement that had hitherto been brought forward. He hoped the discussion would lead to the consideration of what seemed to him to be the most interesting application of cement, viz. the practicability of using it for forming piers or walls in water, where currents prevailed, so as to get rid of the cumbrous and expensive plan of constructing coffer-dams. In 1862, a Paper was read before the Institution, on deep-sea constructions of this nature,[1] at which time the amount of knowledge with regard to cements and bétons was less than it was now. Some facts in the Paper were new to him. One was, that Portland cement appeared to set better in salt water than in fresh water; that was a valuable discovery. Another new point, and in some respects rather alarming, was that this cement was not applicable where there were currents of water. But a considerable extent of sea wall had been, he believed, constructed at Brighton and other places, where Portland cement was largely used, without detriment, in situations exposed to the action of tides and currents. If no further experiments removed the difficulty with respect to the use of Portland cement in moving water, its application to béton piers would be very limited. He thought that in England Engineers were too timid in the application of concrete. Works were often required which would not bear the expense of building coffer-dams; it was, therefore, time this question should be better understood. In France, Engineers who wanted to put a pier in deep water, simply constructed a wooden box in the water, which they filled with béton, of better quality than that which had hitherto been used in this country; and when the work was raised to the level of the surface of the water, they built the masonry upon it with great success, and this plan he was about to carry out, in conjunction with Mr. Barton (M. Inst. C.E.), in Carlingford Bay, in deep water, where it was impossible, with the means at their disposal, to build an ordinary coffer-dam; the depth at low water being 19 feet, and the rise of tide 16 feet more. A wooden box was, in fact, the only covering that could be afforded. The concrete would be deposited in the salt water for a depth of 19 feet, and on that the masonry would be built. The concrete system of construc-

[1] *Vide* 'Minutes of Proceedings Inst. C.E.,' vol. xxii., p. 417.

tion was relied upon with so much confidence, that it was proposed to remove the wood entirely from the back of the structure, leaving it only in front; and as it was evident the front casing could only be temporary, the result would be, that the whole weight of the superstructure, the total height being 46 feet, would rest upon the concrete alone, which would eventually be exposed to the action of the sea. Until this Paper was read, he had resolved to construct that foundation with béton formed of Portland cement; but if the deductions of the Author were true—and it was right to take them as such, from the extreme care with which the experiments were conducted—it would appear that, in this instance, with a rise of tide of 16 feet, it would be inapplicable. He hoped other members would be able to throw more light on the use of Portland cement in such positions, in order that they might judge whether it was prudent to rely upon it, instead of the ordinary hydraulic limes, for the composition of that description of béton. The cost of the wall he had alluded to, on the plan he had proposed, would be about 50*l.* per running foot, while the construction of a coffer-dam would enhance the cost by about 10*l.* to 15*l.* per foot, and the removal of the dam would, under the circumstances stated, endanger the work, and where the pecuniary means at command were limited that risk could not be run.

Mr. Abernethy said the question of the use of Portland cement for the foundations of marine works had been one of great interest to him for many years past, and he had gathered from the Paper one or two facts which he was not previously acquainted with. There was one fact, however, with which all were well acquainted, viz. that the sand used in cement must be sharp and clean; but the information which was most satisfactory to him was, that Portland cement set better in salt water than in fresh.

With regard to the doubts as to employing Portland cement in situations exposed to currents, it occurred to him that if the wooden boxes were used that difficulty would be removed.

Mr. Hemans said the box would be used only up to low-water mark.

Mr. Abernethy added, under those circumstances, the concrete in the box would only be exposed on the surface. He thought Mr. Hemans might safely undertake the work in the

way he proposed, inasmuch as the concrete would be, for a considerable time, protected from the action of the current by the facing of the box.

Mr. Druce said, a large quantity of Portland cement had been used in the pier works at Dover, all of which had been carefully tested, and he could corroborate the opinion, by his own experience, that no detriment to the cement was occasioned by the use of it in salt water. Where currents prevailed, he had found that cement in liquid concrete, from its slow-setting property, was liable to be washed away; but after it was once set it was not affected by them. The difficulty with Portland cement was to obtain it of thoroughly good quality, the demand for it at the present time being beyond the means of supply. With reference to the mode of testing, he had adopted the steelyard system for the last ten years, but he did not think it sufficient. He had met with many instances in which cement, after having stood the ordeal of that machine, and shown high results, had afterwards entirely failed from causes for which the cement-maker was chiefly to blame. The surest way to guard against the effects of inferior or "blowing" cement was to have a sufficient stock on hand to enable it to be thoroughly air-slaked before it was used. Provided it was kept from damp it could not have too much air. His practice at Dover was to expose it to the air for at least one month, which reduced the imperfectly burnt portions to an inert and harmless condition; and since that had been done, faulty cement in the work had become very rare.

A point to be considered was the size of the test-blocks. He believed more reliable results were obtained from blocks having an area of about six inches than from smaller ones. A sure criterion of quality was the weight per bushel, and that depended a great deal upon the burning. As an instance of the little effect produced by currents upon Portland cement, he would state that, in the construction of a small pier on the Sussex coast, Portland cement concrete blocks had been used with satisfactory results, even where exposed to the action of the tide and the constant abrasion of shingle; and it had stood for some years the wear and tear of them. He regarded this as a most valuable cement for hydraulic work, and for very many purposes it was far superior to any other; but the con-

tinuous and careful testing required was a disadvantage connected with its use.

Mr. Robert Rawlinson, C.B., remarked, that some years ago he had acquired considerable experience in the use of hydraulic mortars and cements. If he might be permitted to do so, he would inquire how the Author specified for the mixing of the Portland cement—whether it was mixed on mortar-boards with a shovel, or ground in a pan, or in what way it was mixed; and whether mortar, which had been mixed overnight and stood all night, was allowed to be re-tempered and used in the work. There was one application of Portland cement not generally known, viz. its use, when of good quality, under water, by the aid of a diver. He had used it to make a joint between iron and iron, under a 90-feet head of water, with perfect success, to keep out a quicksand. No other means had enabled him to master that quicksand. He had occasion to sink a well where there was a quicksand at the depth of 90 feet, overlaid by a thick bed of marl, and underlaid by new red sandstone rock. A first well was sunk in the ordinary manner, by miners of the district, and, being an utter failure after two years' work, was abandoned. The second well was sunk within 30 feet of the same site, by 7-feet cylinders, which were sunk without pumping, and lowered by working inside, till they rested on the new red sandstone rock; but the dip of the rock was at such an angle that the 7-feet cylinder could not be made to bed into its surface. He then worked with drills in the sandstone rock, by placing a second cylinder inside the first, with a cast-iron diaphragm bottom, having a 2-feet hole in the centre for the passage of the boring tool; but the difficulty was to make the joint between the two cylinders tight. The ordinary iron cement, of iron borings and sal-ammoniac, would not set, but washed out. He then sent down pure, stiffly-made Portland cement in buckets; this was put in place by divers and set perfectly, where it had remained for three or four years, though exposed to a severe strain by the constant pumping.[1] He should be glad of further information upon the cost of

[1] To close the joint round the bore pipe passed through the diaphragm, Portland cement concrete was used, sent down also in 90 feet of water, spread out and placed by a diver.

Portland cement. All the mortar used at the Liverpool docks —and there could be no better for hydraulic purposes—was made with sea sand, and mixed with salt water. The limestone was from Halkin, in North Wales, was burned at the works, drawn warm from the kiln, slaked on the floor, mixed with 1 part sea sand, $\frac{1}{4}$ part furnace ashes, ground in a revolving pan twenty minutes, and cost, net on the floor of the mill, from 9*s.* to 10*s.* per cubic yard. He thought Portland cement would be, at least, three times that cost. At the Liverpool docks 4 cubic yards of brickwork contained 1 cubic yard of mortar, or in the proportion of 1 to 4. In rubble work the proportion was 3 to 1. In other words, 3 cubic yards of rubble contained 1 cubic yard of mortar. Mr. Hartley abandoned the use of ashlar for facing sea and dock walls, and relied upon granite rubble. The red sandstone ashlar cost about 24*s.* to 30*s.* per cubic yard, and the granite facing rubble, only from 12*s.* to 15*s.* per cubic yard; red sandstone rubble backing cost about 9*s.* per cubic yard. One of the great uses of Portland cement, or mortar like that at the Liverpool docks, would be to enable Engineers to accomplish great works of this class—river walls and dock works —at much less cost than by using the more expensive granite ashlar veneering. Last autumn he visited the works at Cherbourg, than which, as specimens of ashlar masonry, perhaps finer could not be seen. The inner harbour, graving docks, and the several structures on the great breakwater there, were all, however, faced with granite ashlar. To show the misuse of this granite ashlar veneering, he might mention that, probably from a ship coming in contact with it, a considerable length of the said granite ashlar face-work had fallen into the entrance of the harbour, leaving the rubble backing standing, as sound as the day on which it was put up. The casemate forts on the breakwater were splendid specimens of granite ashlar, but they were rent and split in all directions by the giving way of the foundations, and by the impossibility of the mortar, in their beds and joints, holding such work together. If that work had been executed on the plan adopted by Mr. Hartley for the last twenty years, viz. rubble to the face, it would have saved the French Government one-third of the entire expense of those works, and the masonry would have been of much greater strength. Forts, instead of being

faced with ashlar, would be stronger and more fit for their purpose if built with good solid rubble put together with hydraulic mortar, or with Portland cement, of this or of an analogous character. Ashlar would split, and break away in lumps and masses, under the pounding of heavy artillery. Rubble work would not split in like manner, but would rather indent and crush; only the immediate part struck being affected, and small portions being detached.[1]

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[1] The following details relative to Halkin Mountain limestone were subsequently supplied by Mr. Rawlinson. This limestone is obtained from quarries situate near Holywell, Flintshire. Limestone from these quarries has been obtained for the great hydraulic works at the Liverpool docks for the last thirty years.

The following analysis by Dr. S. Musprat, of Liverpool, was made in 1862:—

This hydraulic limestone affords—

Substances soluble in acids	74·726 per cent.
Substances insoluble in acids	25·274 „

These two classes afford the following approximate components—

		Centesimally.
Substances soluble in acids.	Carbonate of lime	71·546
	Carbonate of magnesia	1·348
	Proto-carbonate of iron, Sulphide of iron	1·040
	Alkalies	0·792
Substances insoluble in acids.	Silicic acid	20·068
	Alumina	3·521
	Sesquioxide of iron, &c.	1·192
	Water and carbonaceous matter	0·493
		100·000

The sample of limestone, of which the preceding is a carefully-performed analysis, is of the blue lias variety.

The components, which induce cementation of the mortar under water, exist in this sample of lime to an extent of about one-fourth of its weight. The carbonate of lime and other matters soluble in hydrochloric or nitric acids are in proportion as 1 to 3. The best cement or mortar is obtained from limestones which contain carbonate of lime, magnesia, and clay, naturally commingled in this ratio, of three parts of the former to one of the latter. The quantity of silicic acid and silica which exists in Halkin Mountain limestone, as per sample analyzed, being evenly distributed through its entire mass, is rendered, by calcination of the stone, most favourable to the production of an insoluble crystallized silicate of lime, when made into mortar.

This limestone burns to a yellowish-white colour, producing lime of average whiteness.

At the Liverpool docks, the lime kilns and mortar mills are situate together.

Mr. G. F. White, as a manufacturer of Portland cement, desired to express his high appreciation of the Paper, the details of which were, for the most part, in accord with his own experience. He thought the Meeting would agree with him, that greater intelligence and honesty of purpose could hardly have been brought to the investigation of the subject than had been evinced by the Author, who, whilst consulting, as was his duty, the interest of the public, yet, at the same time, dealt in the fairest manner with those manufacturers who had been brought into contact with him.

In the few remarks he had to make, he should direct attention particularly to the question of the "specific weight" of the cement which the Engineers of the Board of Works had exacted from the manufacturers. It might be remembered that in the year 1852 he had presented a Paper to the Institution, containing "Observations on Artificial Hydraulic, or Portland Cement,"[1] the object of which was, to explain the composition of that material, and to place on record the results of the experiments which had, up to that period, been made on the cement, chiefly by the Engineers of the French Government. For the first few years after its introduction, Portland cement had been supposed, even by Engineers, to be, in part at least, composed of Portland stone. In the Paper referred to he had

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The fresh-burned lime is drawn from the kiln, slaked, mixed with sea sand and furnace ashes, put in the mortar pan, and ground for immediate use.

Best mortar :—	Lime, by measure,	1	part.
	Sand ,,	1	,,
	Ashes ,,	¼	,,
Common mortar :—	Lime ,,	1	,,
	Sand ,,	2	,,
	Ashes ,,	¼	,,

It is ground in pans, which revolve beneath heavy cast-iron rollers, so that the process crushes by partial sliding as well as by grinding.

This mortar on the floor, when made, costs from 8*s*. to 10*s*. per cubic yard.

Random rubble requires about 1 cubic yard of mortar to 3 cubic yards of rubble masonry. Brickwork requires about 1 cubic yard of mortar to 4 cubic yards of brickwork. Grout is made by diluting the best mortar with water until it will pour evenly over the work. Both rubble masonry and brickwork, when used in dock, sea, or river walls, are regularly grouted as the work proceeds, so as to wet the entire mass, and every stone and every brick is bedded, jointed, and covered by grout and mortar, so as to constitute one solid mass.

[1] *Vide* 'Minutes of Proceedings Inst. C.E.,' vol. xi., p. 478.

explained that it was an artificial compound of chalk and clay, the peculiar nature and proportions of which had been quite correctly re-stated in the Paper just read. In introducing a cement of this character it was very necessary to adopt some general standard of excellence, and the Engineers of the Ponts et Chaussées, to whom this cement had been introduced about the year 1850, were not slow in bringing the analyzing powers of the French mind to bear on the subject. They had proposed and applied numerous tests, which had not been materially varied to the present day, and which, for the sake of comparison with the Board of Works tests, might be stated as follows:—

Specific weight .. .. 1200 kilogrammes per mètre, cube, or 103 lbs. per imperial bushel.

Tensile strain, tried on bricks with the same sectional area employed by the Board of Works, viz. 2·25 square inches.

Neat cement	2 days	64 kilogrammes, or	140 lbs. per brick.	
	5 „	128 „	280 „	
	30 „	240 „	530 „	
Cement 1 part } Sand 2 parts } ..	5 „	64 „	140 „	
	30 „	128 „	280 „	

The Engineers of the Board of Works were the first public officials in this country who had instituted analogous tests, though Mr. Rendel, in the year 1852, and Mr. Druce, at a subsequent period, had carefully investigated the subject, in connection with the works at Holyhead and at Dover. The Board of Works tests were of a threefold character: 1st. The cement must be of a given specific weight; 2nd. When gauged neat, it must have a certain resistance to tensile strain; 3rd. It must bear immersion in water, without sign of cracking. The tensile strain, at first fixed at 400 lbs., had been raised to 500 lbs., and the specific weight, fixed originally at 110 lbs., had been raised to 112 lbs. per bushel. It was to this test of 112 lbs. per bushel, which indicated a very heavily burnt cement, that he desired to direct some attention, as pressing severely on the manufacturers, without, as he believed, conferring any corresponding benefit on the Engineer. The way in which it affected the manufacturers was as follows:—In the first place, the less the concentration given to the cement by burning, the greater was the volume of cement that could be obtained from a given quantity of raw material. In other words, if a certain quantity of chalk and clay, calcined to the specific gravity of 104 lbs. per bushel,

produced $21\frac{1}{2}$ bushels of cement to the ton, the same quantity of raw material, burnt to weigh 112 lbs. per bushel, would produce only 20 bushels to the ton, and thus occasion the manufacturer a loss, in volume, of $7\frac{1}{2}$ per cent. Secondly, cement of so high a specific gravity as 112 lbs. involved a much larger consumption of the fuel employed in burning it, an item which, under the most favourable circumstances, counted for nearly one-third of the prime cost of the cement. Thirdly, the destruction of kilns, and of the machinery employed in grinding the cement, was enormously increased by the intensity of the heat required to produce it, and by the hardness of the material to be ground. Fourthly, the quantity of this highly-calcined and heavy cement, that could be produced in any one kiln, bore only a certain proportion to a residue, which was not sufficiently burnt to produce cement weighing 112 lbs., but which could be employed advantageously in the manufacture of cement that was intended to set more quickly, and to weigh only 104 lbs. per bushel. And he might add—what was really, to the makers, the most important consideration of all—that very little, if any, increase of price was given for this heavy cement, over that which was so much less costly in the manufacture.

He would now, however, look at the question as it affected Engineers; and, first, this heavily burnt cement was a dangerous cement to use. It was well known to manufacturers that to be able to push the calcination far enough to produce a cement of a uniform gravity of 112 lbs., it was needful to combine more lime with the clay than was required for lighter burnt cement; and that, in so doing, there was the risk that a perfect amalgamation of the lime and clay would not be effected; but some of the lime, being left in a free state, would be liable to be slaked by water, or even by the moisture of the atmosphere, and produce, sooner or later, the fatal disintegrations which all Engineers had witnessed.

The next consideration was the slowness of the setting of this heavily burnt cement. The Author had stated that it would not set in running water, and that, therefore, he had used means to prevent any water passing over the cement in the sewers during their construction. Now, Portland cement of English manufacture had been successfully employed for concrete *en masse*, in constructing the under-water foundation for

a lighthouse on a coral reef in the Red Sea.[1] It was quite intelligible that, though the cement of 112 lbs. would set too slowly for this purpose, a lighter burnt cement would effect the desired object. To lose sight of this, and to insist that all cement, whatever its destined use, should be thus concentrated in burning, would be simply to deprive it of one of its most valuable properties—that of setting rapidly under water.

Another inconvenience, to which this heavily burnt cement exposed the Engineer, was the almost certainty that it would not be properly ground. Theoretically, the cement should be an impalpable powder, and every grain of sand a matrix, round which the cement should form a film, or coating; but this could scarcely be the case with a material, which it was so difficult to reduce to powder, as the heavy cement in question. On the contrary, if carefully scrutinized, by passing it through a sieve or by washing it, a considerable residue of particles resembling sand would be found, comparatively inert in their character, with very feeble setting properties, and of a nature to diminish the amount of real sand which the cement would otherwise carry. He might also add, that the coarsest ground cement being found to weigh the heaviest, the exaction of a very heavy specific weight, unaccompanied by any other restriction, offered an inducement to imperfect pulverization.

A fourth objection was the loss of volume, which would be sustained by the Engineer, equally with the manufacturer, if he were to become the buyer of cement by the ton, instead of having it furnished through the contractor. The Engineers of France, who almost always bought the cement for the Government works under their charge, were careful to regulate this question, by procuring a cement of sufficient density to pass their tests, while stipulating that it should not exceed that weight, so as to produce a needless loss in volume.

In support of these views, he had compiled the following table, showing the requirements of the Board of Works and of the French Engineers, side by side, and the results of the tests which had been applied to the cement delivered to both of those services during the last five years or six years.

The French tests were made at two days, at five days, and at

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[1] *Vide* 'Minutes of Proceedings Inst. C.E.,' vol. xxiii., p. 1.

RESULTS of Comparative Experiments on Portland Cement. Sectional Area of Briquette—2·25 Square Inches.

NEAT CEMENT.	REQUIREMENTS.				RESULTS.				
	Board of Works. 112 lbs. per Bushel.		French Engineers'. 103 lbs. per Bushel.		Tests as recorded by Mr. Grant. 114 lbs. per Bushel.		White Brothers' Results of Daily Tests from 1860 to 1865. 104 lbs. per Bushel.		
Age when Tested.	Per Briquette.	Per Square Inch.	Per Briquette.	Per Square Inch.	Per Briquette.	Per Sq. Inch.	Per Briquette.	Per Square Inch.	Percentage above required strength.
2 Days ..	..	..	140	62	..	..	298	132	112 above French.
5 ditto ..	..	..	280	124	..	..	437	192	55 ,, ,,
7 ditto ..	500	222	..	..	606	269	560	250	12 above Board of Works.
30 ditto ..	..	..	530	236	Tables 16 and 17. 112 lbs. per Bushel. 708	314	775	344	47·5 above French.
CEMENT 1 PART—SAND 2 PARTS.									
5 Days ..	..	..	140	62	112 lbs. per Bushel. Table 16. ..	..	196	87	40 above French.
7 ditto ..	..	..	..	..	90	40	..	..	
28 ditto ..	..	..	..	..	180	80	288	128	

thirty days, on cement of 103 lbs. or 104 lbs. specific gravity; and it would be observed that the cement supplied to meet these demands had been from 50 per cent. to 100 per cent. in excess of the requirement.

The Board of Works tests had been made at seven days, the requirements being—specific gravity 112 lbs., tensile strain 500 lbs.; and the general average of the whole of the cement supplied for the works of the Metropolitan Main Drainage on the south side of the river Thames had been stated to be—specific gravity 114 lbs., tensile strain 606 lbs., or 270 lbs. per square inch. In one of the Tables (XXXVII.), however, the average strength of cement of 112 lbs. weight per bushel had been shown to be, at seven days, only 501 lbs., or 222 lbs. per square inch—which was on a par with the requirement and no more; while cement weighing but 104 lbs. had acquired, at seven days, a strength of 560 lbs., or 250 lbs. per square inch, being 12 per cent. in excess of the strength exacted by the Engineers of the Metropolitan Board of Works. When mixed with sand, the difference between the two cements was still more marked, for while, at seven days, the cement of 112 lbs. resisted only 90 lbs. per brick, or 40 lbs. per square inch, the cement of 104 lbs. resisted, at five days, a strain of 196 lbs., or 87 lbs. on the square inch, being 40 per cent. in excess of the strength demanded by the French tests, and more than double that of the heavily burnt cement. The comparisons were also in favour of the lighter cement at the age of thirty days, both neat, and with sand.

The only conclusion he could draw from these results was, that the test of specific weight was too variable to be relied on, if unaccompanied with other conditions; that the heavily burnt cement would, very commonly, be coarsely ground, and that it would, in consequence, carry less sand, or, if gauged with two or three parts of sand (the usual proportion), it would be a long time in indurating. As a rule, only one part of sand to one of cement had been used in the sewers, which would, doubtless, make a strong, though it must be confessed a rather costly, mortar. Perfect pulverization was a more essential condition than great specific weight, and a lighter cement, more finely ground, would have carried two parts of sand, and made as good a mortar, at less cost.

The question here involved, however, was not so much one of high quality or low quality, as of the adaptation of different classes of material to various sorts of work. Different works demanded, without doubt, different qualities of cement. Where a long time could be given for induration, a slow-setting cement might be advantageously used; but for tide-work and water-work generally, as well as for the purposes of ordinary building, medium burning, fine grinding, and rapid induration were preferable to the slow induration and the coarse grinding which were the practical concomitants of the heavily burnt cement.

Mr. Carleton Baynes said that he had made experiments on cement weighing 114 lbs. to the bushel, which was moulded, and the bricks then immersed in water for periods varying from one day to seven days, one being broken each day. After one day in water, the cement broke at 275 lbs.; after two days, at 265 lbs., owing to a fracture in the mould; after three days, at 520 lbs.; after four days, at 580 lbs.; after five days, at 570 lbs.; after six days, at 765 lbs.; and after seven days, at 890 lbs. Another set of moulds, from a similar parcel, broke on the second day at from 254 lbs. to 378 lbs.

The test was excellent, and specially suited to the work in question; but he would suggest that there should be some limit, for, to judge from the tables, the cement of 123 lbs. to the bushel would be very superior to that of 112 lbs. to the bushel. He considered that the cement of 112 lbs., *cæteris paribus*, would be a better cement than that of 123 lbs., on account of the slowness of setting of the latter. It was indeed quite a different cement to work from that of 112 lbs., and that, in its turn, was quite different from a cement of 104 lbs. The hard-burnt cement was not generally useful; the builder and plasterer would be much disappointed if it were sent to them, and in tide-work a slow-setting cement was not desirable. In an article which was sold by the bushel, bulk was a thing to be desired, and if equal efficiency was attainable with a less specific weight, the lighter cement was preferable.

The conditions demanded for general purposes were—to cover the greatest extent of surface, to be of uniform colour and setting power, and not to crack, or peel off from the brick-work; the breaking test would be of little service in obtaining these conditions.

There was probably no manufactured article which depended so much for its excellence on the manipulation it received as cement. Thousands of tons of good cement were spoilt by being improperly gauged, or by being gauged a second time after having partially set, and oftentimes first-rate cement was condemned because a mason had not been accustomed to its particular way of setting. On great works, where large stores of cement must necessarily be kept, it was desirable that, instead of being stowed in bags, as was generally the custom, it should be shot in a large shed, and occasionally turned over. It would be as much to the interest of the Engineer as to that of the contractor, because the cement would be greatly improved by it. The cement was sometimes taken from the manufacturers quite hot and stored in bags, tons and tons over each other, and it had no chance of cooling, but was almost certain to "blow" in the work.

In reply to an inquiry, Mr. Baynes said, in objecting to a heavy cement as being slow setting, he referred particularly to that weighing 123 lbs. per bushel. He was led to desire a limit to the specific weight required in cement, because it might be supposed, if cement was burnt to 130 lbs., it would be better than that which was burnt to only 123 lbs. When this heavy cement was gauged, it would not set enough to be taken out of the mould for a long time; it had then to be coaxed into the water, and after all, three moulds or four moulds would often run together in the water, and the moulds would not keep their edges, though they stood this enormous breaking test. If, however, it had been tide-work, it could not have been humoured in that way. It was frequently requisite to let the cement set for hours, after being taken out of the mould, before putting it into the water; and of those briquettes, many would have to be trimmed to go into the machine, so as to be tested and broken.

Mr. C. L. Francis thought there was yet much to learn from the analysis of the materials of which cement was composed, as well as in its uses and application. Cements of so great weight were costly and inconvenient to the manufacturer, and should be costly to the consumer. It was stated in the Paper that bricks of neat Portland cement, after being made three months, six months, and nine months, withstood a crushing force

of 65 tons, 92 tons, and 102 tons respectively, or were equal in strength to the best quality of Staffordshire blue bricks; and that bricks of the same cement mixed with four parts and five parts of sand, bore a pressure equal to the best picked stock bricks; while Portland stone of similar size bore, on its bed, a crushing weight of 47 tons, and against its bed somewhat less, and Bramley Fall stone sustained on its bed $93\frac{1}{3}$ tons, and against its bed $54\frac{2}{3}$ tons. Portland stone crushed easier than the lowest experiment with Portland cement. Where, then, was the practical use of having a cement stronger than the material which had to be joined together? If the stone decayed what were the joints good for? He believed that cement of from 100 lbs. to 103 lbs. would last as long as any materials it could unite. With respect to the preliminary experiments made with samples of Portland cement, of the average weight of 108·6 lbs. per bushel, it appeared that they sustained breaking or tensile strains varying from 75 lbs. to 719 lbs. upon $2\frac{1}{4}$ square inches. Manufacturers produced cements of different weights and quality. In his own case, he generally manufactured cement weighing from 100 lbs. to 104 lbs. per bushel, and he thought to make it from 112 lbs. to 114 lbs. was quite a superfluous strength; and when such a difference as between 75 lbs. and 719 lbs. was shown, it ought to be known whether the same description of cement was used, otherwise the experiment could not be regarded as a fair one. But the great question to be considered was, the advantage to be gained by having a cement stronger than the material it had to unite, and therefore unnecessarily costly.

Mr. J. W. BAZALGETTE felt it to be his duty to bear testimony to the great care which was taken by the Author in conducting these experiments. The facts laid before the Institution were nothing but the naked truth. He believed that great good had been done by the tests; that the manufacture of cement had been improved thereby; and that Portland cement was destined to be used to a much larger extent than it had been hitherto in engineering works. In many cases Portland cement would bear admixture with sand, so as to enable it to compete in price with common mortar, and secure greater strength in the work at the same expenditure. The time would probably arrive when all Engineers would test

their own cement, and would obtain the best that was to be had; and those tests would give more confidence than the character of any firm, although much value should always be attached to the character of the manufacturer, and would yet improve the manufacture of cement. He regarded the test of weight as one of considerable importance. It had been ingeniously suggested that the weight of 112 lbs. per bushel was adopted because it was 1 cwt.; and twenty sacks of cement made a ton; but, as would be seen from the Paper, 110 lbs. to the striked bushel was first adopted, not 1 cwt. That weight was selected after careful experiments; and if, after obtaining these results, it was found by further experience and experiments that it might be increased with advantage, it was a proof that an excessive weight had not been chosen in the first instance. That the heavier cements bore the greatest strain was clearly found to be the case. An examination of the tables would show that, as a rule, the cement burned to weigh 112 lbs. and upwards would bear a considerably greater strain than cement of less weight; that it was in fact the best, and there was no exception to that rule. A manufacturer's experiments upon his own cement could hardly be accepted, in contrast with experiments made by impartial and independent persons upon the cements of various other manufacturers, taking the cement from the bulk—good and bad together—and gauged perhaps not under the same advantages as would probably be secured by the manufacturer testing for himself. Then it had been argued that if the cement was stronger than the materials which it had to unite, it was not surprising that the manufacturer should be unwilling to raise the standard of quality. But he had yet to learn that any cement had been obtained which was "too good." When that pitch was arrived at, it could readily be diluted with a larger amount of sand, and its cost and its strength could be reduced at pleasure. It was the Engineers' duty to raise the standard of quality, and when it had fairly been determined what was the best material, it would always command its price in the market, and that would determine the question which was the most marketable article to produce.

With reference to the setting of Portland cement in running water, he did not know that there was greater objection to using Portland cement in running water than any other kind of

cement. If care were not taken, all cements would be washed out by the mechanical action of the water; therefore the more rapidly it set, the less it was subject to that action, and the more cement was retained. In his experience, Portland cement did set perfectly well under water; but with any cement, if concrete was loosely thrown into the water, the gravel would descend to the bottom more rapidly than the cement, because its specific gravity was greater, and thus concrete so used would become deteriorated in quality.

Mr. Kinipple remarked that the Author had stated that "Portland cement concrete, made in the proportions of 1 of cement to 8 of ballast, in some cases, and of 1 to 6 in others, had been extensively used for the foundations of the river wall, piers of reservoir, and foundations generally at Crossness and Deptford, with the most perfect success." Now to have obtained such perfect success, it must have been absolutely necessary to have kept the entire works clear of water, for it was not possible to get good concrete under water, whether quiet or not, if it was thrown in dry immediately after mixing. He had ascertained that in only 1 inch of quiet water, concrete, made in the proportions of 3 to 1, was endangered by the working out of the silicates, or the best of the cement, from the ballast; those silicates resembled slime on the surface, and with the slightest motion or run of water were lost. In concreting an outer apron just inside a coffer-dam at low water, he had used Portland cement concrete, in the proportions of 4 of ballast to 1 of cement. It was all put in at the same time, in the same manner, with the same cement and ballast, and by the same men, and was allowed to remain in quiet water for three months. When he had again occasion to examine it, the concrete nearest the abutments was sound and hard, but in the centre, or rather in the part last closed in, it was quite soft; in fact it was ballast, with a mere fraction of cement retained in it. This was executed in about 2 inches of quiet water, and had to be removed for the insertion of fresh concrete. To avoid this for the future, he had resolved that all Portland cement concrete should be mixed on the surface, and allowed to set for several hours; the length of time for setting to be in proportion to the quantity of the cement used, and when set, to be used in a crumbled condition. By experiments he found that

he was able to retain nearly the whole of the cement, without any loss as to strength.

He then referred to several specimens which he exhibited. No. 1 was composed of 1 part of Portland cement, weighing 114 lbs. to the bushel, and 1 of fine river ballast; this was thrown into 6 inches of quiet water, dry, immediately after being mixed, and was submerged eighteen days, at the expiration of which time it showed the great separation, even in quiet water, which had taken place. Specimen No. 2, similarly composed, was also thrown into 6 inches of quiet water, but not until it had been allowed to set, after being mixed for five hours in the open air, previously to being submerged for eighteen days. This specimen was so hard that it had to be split by a cold chisel and hammer, and had retained nearly the whole of the cement. Passing dry concrete down shoots would not prevent the separation, as the larger stones rolled out and set the cement free. If mixed and allowed to set a day or so, it would without doubt be a success. As to the mode of executing brickwork free from a current of water, he agreed generally with the Author, but he did not think that all bricks should be thoroughly saturated with water. For tidal work, such as wharf walls, river wings, &c., Roman cement stood the "wash" best, lias lime next, and Portland cement last. A joint was seldom lost in Roman cement compo brickwork, in lias lime mortar now and then, but in Portland cement compo there was great difficulty in preventing sometimes six or more courses being destroyed in one tide, from the loss of the joints. Portland cement brickwork, covered twice by water in twenty-four hours, should be made with compo as stiff as it was possible to use it. The bricks should be perfectly dry, cleansed from the maker's sand, the face joints raked out for a depth of 1 inch whilst green, and pointed, temporarily, with Rochester yellow clay. The clay joints would last many days, and by the time the clay joints were washed away, the cement work would be perfectly set, and could then be pointed in neat cement. Work executed in the manner described seldom failed, and was free from many of the consequences of the running of the joints. Complaints were often made of the badness, or rather of the irregular qualities of Portland cement. He believed, in many cases, those complaints were chiefly due to the manner in

which it was applied to uses so varied in their character. He would recommend, for all brickwork executed under water, that the joints of compo should be dispensed with, that the bricks should be coated with compo, and be allowed to set out of water some hours, and be then rubbed together in position under water. Specimen No. 3 showed nine bricks moulded, or coated, in neat Portland cement, of an average thickness of 3·16ths of an inch, allowed half an hour to set in the open air, rubbed together into the present form in agitated water, and kept submerged for eighteen days. Specimen No. 4 showed a better result. Nine ordinary stock bricks were coated, as before, in neat cement, then allowed five hours to set in the open air, afterwards rubbed together under agitated dirty water, and kept submerged for eighteen days. Both these experiments went to prove that jointless work in almost any working depth of water, whether clear or muddy, or where there was a great current, could be executed with perfect success. The specimens were not disturbed from the time they were submerged until they were taken out, when the work was found to be thoroughly sound.

The statement as to the making of a joint to a mining pump pipe, under water at a considerable depth, was interesting, and proved what might be done with Portland cement under water. Joints might be caulked under water with cement nearly set, and broken in pieces about the size of a pea. He had frequently made use of neat cement for grouting between sheet piles, with perfect success; in one case under water, the cement, in its descent or settling down, drove out the clear water, and filled every crevice; within ten days it was hard enough to resist a chisel point. Model No. 5 showed blocks of concrete coated with compo in the same way as the specimen bricks, guided into position by rods or chains, built on a concrete foundation, the face joints caulked with cement or soft wood wedges, and the chains or light rods grouted in with neat cement.

Mr. Kinipple added that the concrete out of which the cement had been washed was mixed in the ordinary way. He suggested, in order to ensure success, that the proportions should be accurately measured in the usual way, mixed together dry, and water added by means of a common watering-pot; the mass

then turned over, and afterwards separated and allowed to remain for some hours in layers of 3 inches or 4 inches thick, exposed to the open air; and when it became so tough that it would not receive an impression from the hand, it was ready to be turned over again and passed into the water. By working it in that way he had retained the whole of the cement.

Mr. John Aird, jun., said, from the opportunities he had had of witnessing the experiments conducted by the Author, he could bear testimony to the great care bestowed on them. He believed they had been carried out in the most conscientious manner, and with every desire to do justice to all the manufacturers whose cement was operated upon. He thought there was some mistake as to the concrete being thrown in quite dry. That certainly was not the plan adopted at Deptford; for there it was previously mixed with a moderate amount of water, then thrown into the work, and in all instances where Portland cement was used it was perfectly successful. In his opinion, the quality of the cement could not be too good; but having got that, the Engineer must look to the nature of the work to be carried out, and determine the extent to which inferior materials (always more readily obtainable) should be employed. With regard to the influence of water upon cements, his experience led him to believe that Roman cement was better suited in some few cases. For instance, for facing work to river walls, when it was subject to the rise and fall of the tide. The probability was, that even if the greatest care was taken, Portland cement would, to a certain extent, be washed away. Much better results would be obtained by the use of Roman cement, as that soon set, and became quite firm before the water rose and destroyed it.

Sir Charles Fox would mention an interesting instance, in which the difficulty of putting concrete into running water was successfully overcome in a simple manner. In forming the foundations of the Rochester bridge, the cylinders were sunk 42 feet below the bed of the river; being a tidal river there was in those cylinders a good deal of what the workmen called "breathing;" in other words, the water rose about a foot at the bottom of the cylinder, and then receded, and continued to rise and fall as it was supposed by simple momentum. It was found that, as a consequence, all the cement in the concrete,

when placed at the bottom of the cylinder, was washed out and came to the surface, so that for 9 inches or 10 inches at the bottom only ballast remained. The difficulty was got over in the following manner:—A quantity of concrete having been prepared, a piece of stout canvas sail-cloth, such as was used for hose-pipes, was cut one foot larger in diameter than the bottom of the cylinder. When the water subsided, the sail-cloth was spread over the surface at the bottom of the cylinder, to which it was well fitted all round, and when covered with about 2 feet of concrete, it held down the water until the remaining concrete was deposited safely upon it. In that case Portland cement was used. The same plan was adopted with all the cylinders for those foundations.

Mr. G. Dines remarked that he had had considerable experience with Portland cement, from its first introduction to the present time, and had experimented largely, both for himself and for the late Mr. Thomas Cubitt, as to its tensile, transverse, and crushing strengths. The strongest piece of Portland cement he had tried broke with a strain equal to 739 lbs. per square inch, the average was 558 lbs. The pieces experimented on were made of neat cement, without sand. That material was much stronger than Portland stone, which bore a tensile strain averaging 332 lbs., while Sicilian marble was equal to 1073 lbs., or double that of Portland cement. For brickwork and river walls Portland cement was most valuable, and it was sometimes used in ordinary mortar, if the mortar was required to be of extra strength. When it was used for stucco it frequently gave much trouble, and the makers had yet something to learn about its properties. It was very different to Roman cement, as regarded expansion and contraction; and for purposes for which he had used Portland cement he was obliged to go back to Roman. Some long pieces of Roman and of Portland cement had stood in his office for some time, and he found the Portland cement, although made perfectly straight, was twisted like a piece of green deal, while the Roman cement remained perfectly true. He had seen Portland cement, where used for the coping of a wall, buckled up, so as to let the light through between it and the wall, and when he began a work with Portland cement, he hardly knew when he should finish it. He feared that it had a corrosive effect upon

iron; therefore when cement had to be in contact with iron he always used Roman.

Mr. Scott Russell said Portland cement had been extensively used in the insides of ships, to preserve the iron from corrosion; and after eighteen years' use, he had seen Portland cement dug out of an iron ship, when the red-lead paint and the skin of the iron were as sound as on the day they were put there.

Mr. Henry Maudslay said this fact appeared to show that the cement had not been in actual contact with the iron, as it was protected by the red-lead paint, to the extent probably of two or three thick coats. The caution raised with reference to the effects of Portland cement in contact with wrought iron had been made upon the supposition of fact which did not appear to exist.

Mr. Scott Russell observed that the inference to be drawn from Mr. Maudslay's observation would be that wherever cement was used with iron, the iron should be painted with red-lead.

Mr. Joseph Jennings said that when he had used Roman cement, where it was subject to tidal influence, it had produced sound work, although the tide had returned in five minutes; while Portland cement, under the same circumstances, had become perfectly fluid. He had used Portland cement for filling up, as concrete, between stones at the bottom of a river, and had experienced the difficulty occasioned by the cement washing out, and he had found, upon examination by divers, six months or eight months afterwards, that the Portland cement which had been put in between the stones with trunks and divers had washed out, whereas the Roman cement, with which the bottom of another lock had been repaired when the water was out, stood perfectly well, although the water was allowed to flow over it within five minutes after the time of its being put in: yet for many purposes of construction Portland cement was no doubt a most valuable material.

There was one point which he thought had not been quite sufficiently considered in the Paper, which was, that of the extent to which cement might be used in the form of concrete blocks, in buildings. He believed that, in a few years, a much larger proportion of cement blocks would be used for building purposes, such as dock walls, in the same way as they were

now used at Dover. With this heavy Portland cement a large portion of gravel and sand could be mixed, and by that means much stronger work could be executed than any brickwork in general use; and therefore it was most important to consider in what form the Portland cement could be most profitably employed in these concrete blocks, as an artificial stone for use in London. At the present time the great expense of stone was a serious consideration, but cement blocks, if large, would, he believed, almost entirely obviate the use of stone for many purposes. With regard to this point he should be glad to hear how far the shingle, which was now being used, and which to a great extent had been deprived of all angular points, had a disadvantage, as compared with the use of angular stones, in forming these concrete blocks. He was not aware that it had been used to any great extent in the form of angular gravel. The blocks at Dover and at Brighton were all formed with the ordinary sea shingle. Another point was the effect of fire upon Portland cement, when employed in the construction of furnaces of various kinds. As far as his own experience went, he thought Portland cement would stand in furnace work better than Roman cement.

Mr. Thomas Bevan remarked, in reference to the Tables appended to the Paper, that it would be found that the large manufacturers, in high repute with foreign Engineers, supplied cements with a breaking strain which, although equal to the requirement, was lower than that of the firms which furnished the chief quantities to the Main Drainage Works. No hasty inference should be deduced from this. He was persuaded that the Author would be the first to admit that those manufacturers could, if they liked, produce cement to break at a much higher strain. It should be remembered that a high breaking test could only be produced by an extra expense in the manufacture. It would cost at least 3*d*. to 4*d*. per bushel extra to break at 700 lbs. than it would to break at 500 lbs. If the Author was consequently satisfied, as was the case at first, with 400 lbs., it was not surprising that those firms which had a full demand for their cement, and a well-established business, should be content when they gave from 500 lbs. to 550 lbs.; as to have given more would have occasioned a much enhanced cost. While, on the other hand, it was perfectly intelligible that

other firms should be willing to incur a sacrifice, in order to attain a higher result. As a manufacturer, he desired it to be understood that there was no fair ground for any trade use being made of these Tables, to the disparagement of the large manufacturers. The comparison, moreover, of the breaking tests of cement of the same specific weight, but made by different manufacturers, could not, within certain limits, lead to any conclusion, to the depreciation of either. Provided that he was safely above the test of the Engineer, a manufacturer would desire to make not only what would be most economical in the burning, but what would be most safe. Attention had been drawn to the necessity of working with a maximum of chalk and a minimum of clay, in order to secure a high breaking test. But even in more moderate tests it would be found that a different breaking strain would result at the same specific weight, according as more or less clay was used in the composition. In fact, the more clay was used without deteriorating any of the qualities of the cement, except by a little reducing the breaking strain, the "kindlier," to use the language of the workman, would be the cement; and the more chalk was used, within those same limits, the more "hungry" and more difficult to work would be the cement, although it would certainly bear a higher breaking strain. It was not to be assumed therefore that if cements of the same specific gravity broke unequally within certain limits, that there was necessarily any superiority or better composition in the manufacture of either, but only that one had more, or less, clay than the other. He was of opinion that the test of 500 lbs. in seven days was not an undue one; practically, it was little, if at all, more than the old test of 400 lbs., as that test was first used. The application of a breaking test upon any briquette of Portland cement depended altogether upon the quantity of water used in gauging it. Working men who constantly manipulated these tests, after a time became exceedingly expert in gauging, and insensibly acquired the habit of gauging with a minimum of water. A brick made with a minimum of water would bear a much higher strain than one gauged with sufficient water to make a good stiff paste. Any Engineer who might doubt this experiment would see it at once if he tried cement gauged with two parts of sand, and broke the briquette against one

similarly composed, but to which was added a good dose of water. The results, as it would tell more when sand was mixed, would be 50 per cent. wide. It was well known by those who were in the habit of supplying the French Engineers, that the breaking machine in use by the Ponts et Chaussées and the Imperial Marine was widely different from that employed by the Author, and at least 25 per cent. more unfavourable to the brick. It was a simple clamp, and the brick was usually broken with a jerk, by the gradual addition of weight in the most primitive manner, while the Author's machine was a regulated steelyard. Therefore, if the test was attainable upon the French machine, it would be much more so upon one so favourably constructed as the latter. The argument that a good and highly breaking cement could be made of a less specific gravity than 112 lbs. might be conceded; but that the same cement that would break well at 104 lbs. would break still higher at 112 lbs. could not be denied. He was of opinion, therefore, on the whole, that the actual test, so far from being an inconvenience or a disadvantage to the manufacturer, was a benefit, because it separated the genuine Portland cement from many counterfeits that bore its name. An objection was taken to a seven days' test, and an inquiry made if an earlier test could not be used. The Admiralty had used a test of forty hours and sixty hours, and his impression was that it was possible for bad cement of one particular description to pass that test—he meant over-limed cement; but certainly none of this could pass a seven days' test. It would discover itself by defective arrises and small cracks before that time. He thought the test at seven days was the best, and that the tests of forty hours and sixty hours were quite unsuitable for a slow-setting cement. In forty hours and sixty hours cement of 104 lbs. to the bushel would perhaps break as well as cement of 112 lbs., but it was in the longer dates that the superiority of the heavier cement was to be seen. If it was suspected that cement was over-limed, and if it was desirable to form a judgment before seven days, a small pat gauged neat might be put in water, immediately after it was set, and left unprotected. The thin edges would fly much more quickly in this way than would be the case in a brick in a mould. It was interesting to hear that Portland cement withstood a higher strain than the materials for which

it was used as mortar. It would seem that the argument that such excessive strength was unnecessary should give way to the consideration that with the possession of good cement—cement stronger than the materials—it was time to procure better bricks and better materials.

Mr. J. A. LONGRIDGE said a question was raised in reference to the use of salt water in slaking cement and lime. He had been accustomed for years to use sea water for that purpose, and had always found it succeed quite as well as fresh water. He had also largely used sand of the sea-shore, impregnated with salt, and he had found the lime set as well with that as with other sand, provided it was sharp sand. But a more interesting case was that which was being carried out at Port Saïd, in connection with the Suez Canal. The last time he passed through Egypt he was informed by one of the Engineers that salt water was being used for slaking the lime, and that sea sand alone, and without any gravel or stones, was being employed for the concrete for the piers. It was a bold experiment, but it appeared to be exceedingly successful. He had since received from M. de Lesseps a copy of the specification, according to which the concrete was made, accompanied by a letter, stating that sea water was used exclusively, copies of which are annexed. The blocks were about 11 feet 6 inches long, by 5 feet by 7 feet, and they were required by the specification to be made two months before being immersed. The work done amounted on an average to about 220 cubic yards per day.

(Copy.)

"Renseignements sur les jetées de Port Saïd.—No. 5968.

"MONSIEUR, "*Paris, le* 26 *Décembre*, 1865.

"En réponse à la lettre que vous avez adressée le 22 courant à M. le Président de la Compagnie, j'ai l'honneur de vous adresser ci contre, un extrait du marché que nous avons passé avec Dussand frères pour la construction des jetées de Port Saïd, extrait qui répond à la plus grande partie de vos questions.

"Je dois ajouter pour compléter ces renseignements que le ciment est traité à l'eau de mer exclusivement, et que nous immergeons par jour environ 170 mètres cubes de blocs de béton.

"Agréez, Monsieur, l'assurance de ma considération distinguée,

(Signed) "CADIAT.

"L'Ingénieur, Chef du Service de Paris, à Monsieur James Longridge, Abingdon Street, No. 18, Westminster, à Londres."

"EXTRAITS du Marché Dussand pour l'exécution des Jetées de Port Saïd en Blocs artificiels.

"Les jetées à construire doivent avoir, celles de l'ouest, une longueur d'environ deux trois mille trois cents mètres; celle de l'est, une longueur d'environ deux mille mètres.

"Elles seront construites sur le même profil, lequel présente un couronnement horizontal de cinq mètres de largeur, émergeant de deux mètres au dessus du niveau moyen de la Mediterranée, avec des talus à quarante-cinq degrés.

"Les blocs auront trois mètres quarante centimètres de longueur, deux mètres de largeur, et un mètre cinquante centimètres de hauteur, soit, déduction faite des rainures, un cube de dix mètres.

"Une partie du massif des jetées pourra être faite avec des blocs de quatre mètres cubes, sous la condition expresse que les revêtements extérieurs seront composés exclusivement de blocs de dix mètres.

"Les blocs de l'une et l'autre catégorie seront formés de sable de la plage et de chaux du Theil, dans la proportion de trois cents vingt-cinq kilogrammes (325 kls.) de chaux en poudre sèche pour un mètre ($1^{m.}$ 3) de sable. La Cie. se réserve le droit de faire varier le dosage de la chaux jusqu'à concurrence de vingt-cinq kilogrammes (25 kls.) en plus ou en moins de la proportion indiquée.

"La chaux proviendra des fours de M. Savin de la Farge au Theil (Ardèche), ou elle sera de toute autre provenance, donnant une chaux de quantité egale et acceptée par la Cie. Toutes les enveloppes porteront la marque du fournisseur.

"Les blocs demeureront soumis à la dessiccation à l'air libre pendant deux mois ou moins, sauf les réductions de délai qui pourra autoriser le Directeur Général des Travaux en cour d'exécution."

Mr. Longridge added, that Portland cement was not used at Port Saïd, but a hydraulic lime brought from Theil, in Ardèche —a lias lime, he believed, but the specification gave the name of the manufacturer. His own experience had been chiefly with hydraulic lime, and coral lime which had no hydraulic properties, and with the latter he had used sea sand for outside work, and found it to set well.

Mr. SCOTT RUSSELL said he had been requested to inquire what was the kind of sand with which the cement was mixed? He did not put this question from any impression of his own, it was suggested to him by Mr. Harrison, who had had great experience in the use of cements, and who said that, according as the sand used with the cement had been formed by the sea from one substance or another substance, he got most variable returns; and that what was called Thames sand was mainly the sand of flint, and on the other hand, the sand found on the western coast was to a great extent formed from limestone. It

was therefore obvious if a fine sand formed from limestone was mixed with cement, the result would be different from that of sand which was formed from flint. He would ask whether any experiments had been made in which the quality and nature of the sand had been examined as closely as the quality and nature of the cement?

Mr. Cockburn Curtis said his experience and observations led him to believe that great advantage was derived from mixing the mortar, cement, or concrete, intended to be used in submarine, coast, or estuary works, with salt or brackish water, of the same character as that in which the works would eventually be submerged. The minute component elements of salt water had not yet been ascertained with the degree of precision which was essential in forming a correct theory on this branch of the subject; but able chemists had asserted that it contained small proportions of acids, and it was probably by those acids that the mortar and cement, if mixed with fresh water, were acted upon when submerged. The difference in specific gravity between fresh and salt water, although small, was of sufficient importance to be taken into consideration. Fresh-water rocks frequently became disintegrated when exposed to the chemical action of salt or brackish water, and for that reason he considered it desirable, in the construction of such works in béton or concrete, to use the sand, shingle, or other materials found on the foreshore or beach from which the particles subject to the chemical action of salt water had already been removed.

Mr. Vignoles said that more than twenty years ago French Engineers employed salt water in making concrete blocks for Algiers, but many of those blocks (whether from the fact of their having been formed of concrete mixed with salt water, or from some supposed chemical action of the waters of the Mediterranean) had become disintegrated, and considerable destruction had taken place, though the great mass still remained in position. At the new port of Marseilles salt water was used for the concrete blocks with greater success. It was, therefore, of no recent application. He would observe, that having been on more than one occasion compelled, in foreign countries, to make his own hydraulic cement, he found the great principle of perfection was drying the clay as much as

possible, either in the sun or by artificial means previous to baking it. Having dried it in a more perfect manner than was generally done, the degree of baking was regulated to be as little as possible, done slowly, and only just sufficient to accomplish the object without affecting the properties of the clay. When so burned the material could be reduced under rollers to an impalpable powder; used in that state it was most successful, and the specific gravity was higher than if it had not been so perfectly treated. A scientific reason was thus afforded in favour of weight, because the specific gravity became a test of the good burning and preparation of the cement.

Mr. C. B. Lane remarked that the axiom "no chain is stronger than its weakest link," was an established mechanical principle, and that the argument based on that principle had not, he thought, been answered. It occurred to him that if the Author, in making these experiments, had supplemented them with a series of experiments upon pieces of brick clay cast in the same moulds and properly burnt, he would, so soon as he had arrived at equality of cohesion between the brick and the cement, have solved the question not only mechanically, but also commercially and economically; and any expenditure for procuring a material beyond the cohesive strength of the brick was so much labour lost. Having arrived at what might be called an equation of values, to endeavour to increase one side of that equation without increasing the other appeared to be incurring an expenditure which was hardly justified. With respect to the argument of competition, more than one of the great cement-makers had stated that they had not supplied cement for these works. It therefore appeared that the limits of competition had been rather narrowed than widened by the processes followed. The great prospective advantages that were anticipated, and which would in all probability be obtained, when they did accrue would be for the benefit of future works, but not for the works which had paid for them. With respect to the relative merits of blue lias lime and Portland cement, he thought that a great portion of these works might have been constructed with blue lias lime; at the same time it might be argued that it was all-important, in the streets of London, to use a material which would lead to the completion

of the work with the greatest rapidity; but there were many districts in which blue lias lime might have been substituted for Portland cement (perhaps in most cases for concrete) with a considerable saving of expenditure.

Mr. F. J. Bramwell thought that a humble view had been taken of the duties of Engineers in high position, when it was argued that it was not a part of that duty to experiment for the benefit of posterity. For his own part, he believed an Engineer eminent in his profession, and entrusted with large and important works, could not do better service than to endeavour to raise the standard of work carried out under his directions; and those who had inspected the character of the work executed under the superintendence of Mr. Bazalgette and Mr. Grant, must acknowledge that those gentlemen had raised the standard of work in such a manner as to deserve the thanks of the profession.

With regard to cement, he thought it one of the most important subjects that Engineers connected with structures in brickwork could consider, because clearly there was no use in having good bricks to build with, unless they had also good means of fastening them together, that was to say, one great difficulty Engineers had to contend with was the means of attachment of the material; therefore he thought time was well bestowed upon the consideration of the question. Mr. Grant came before them with so many years' experience, and with the results of so many thousands of experiments, that it was almost impossible for anybody, except those who had been engaged in the manufacture, and had been in the habit of making daily experiments, to speak with any confidence on this subject in the face of the numerous experiments which had been made by Mr. Grant. That gentleman had started in effect, that there were three tests which the cement must satisfy before it could be pronounced to be thoroughly good; one as to strength at various ages, neat and mixed; the second as to the power of resisting water; and the third, the test of weight per bushel. The latter test was the only one as to the propriety of which any difference of opinion had been expressed. For his own part he would say, as soon as he heard of the test by weight, he was struck with the difficulty of correctly ascertaining what the weight was, because he knew by experience that when dealing

with granulated matter it was almost impossible, even with the greatest care, to get uniformity of condition in the respective trails, that was to say, to get the same amount of granulated material into a particular measure. In corroboration of this he would state the results of what he had tried lately. A quantity of cement was poured into a bushel measure by a man accustomed to the work, and struck off level; it then weighed 107 lbs. exclusive of the weight of the measure. Then another portion of the same cement was poured slowly out of the sack down an inclined board into the bushel measure, and it then weighed only 97 lbs.; he then had it shaken down in the measure, and the weight then got up to 132 lbs. When it was found, therefore, with the same measure of capacity and with the same material, there could be a variation of from 97 lbs. to 132 lbs., he could not help thinking if a test of gravity could be obtained which was not liable to those variations, it would be a very desirable thing. Until the mode of ascertaining the weight was altered so as not to be affected by the question as to whether, in the trial, the cement was more compact in the measure, he thought that the stipulation as to weight—though probably the manufacturers did not wish to have any more tests imposed—should be combined with that of sifting, so as to ensure the fine grinding of the cement, as if this were not done he thought the requirement as to weight was liable to act as a premium for coarse grinding. In reference to this, he would state that he had sifted through a sieve with 900 holes to the square inch, a certain portion of the cement which weighed as before stated, when very carefully put into the measure, 97 lbs., and when put in the ordinary way 107 lbs., to the bushel; those portions which would not go through the sieve were then poured into the bushel measure with the same care as that which made the unsifted weigh, as previously stated, only 97 lbs.; with this care the coarse weighed as much as 101 lbs., and when shaken down hard into the measure, 144 lbs., whereas the unsifted cement weighed, as before stated, only 132 lbs. He then took by themselves the fine particles which had passed through the sieve, and they then weighed only 98 lbs. as against 97 lbs., and, when shaken, 130 lbs. as against 132 lbs. for the mixed and 144 lbs. for the coarse. He gathered from this that weight, as ascertained by pouring the material into a

measure, was liable to extremely variable results, even when the greatest care was taken; and further, that unless it was accompanied by the test of sifting there might and probably would be badly ground cement present in the mass. That being so, and agreeing as he did in the importance of the test of weight, it occurred to him that a means of ascertaining the true weight for cement might be adopted similar to that which was employed for ascertaining that of gunpowder, and which means had been shown to him by Mr. Abel, of Woolwich Arsenal. The mode pursued in ascertaining the gravity of gunpowder was in effect this:—A vessel capable of containing a known weight of mercury was employed; then a known weight of gunpowder was taken and put into the vessel, and thereby a bulk of mercury equal to that of the grains of gunpowder was displaced, and this exact bulk could be ascertained by the diminished weight of the bottle. Thus the weight of the cement having been known and its bulk ascertained, its specific gravity was at once determinable. Mr. Abel kindly allowed one of Mr. Bramwell's assistants to use the apparatus to test the gravity of cement; but it was found that the liquid used, viz. mercury, was not suitable as a test for so finely powdered a material as cement; but by using turpentine as the liquid, the gravity had been ascertained without difficulty, and he found the specific gravity of the cement before mentioned, which, as put into the bushel measure, weighed, as before stated, the 107 lbs., was 3·11. Now 3·11, it would be found, was equal to a weight per bushel of 249 lbs., so that if that cement could be obtained in a really solid state, it would weigh 249 lbs. instead of 107 lbs. 120 lbs. cement was equal to a specific gravity of only 1·5, and 104 lbs. was equal to only 1·3 as it lay in the bushel. The way in which the gravity was taken was this:—A phial, holding when filled to a certain point a known quantity of turpentine, was taken, and a certain weight of cement was put into it. It was then filled up to the marked point; the contents were weighed, and the excess of weight found was clearly that which was due to the weight of the cement above that of the turpentine which it displaced, and in that way the gravity was ascertained. Whether it would be possible to employ so refined a test as this in practice he was not prepared to say. He thought Mr. Grant would tell them it was not.

Then came the next question, which was, whether this insistance of great weight in cement was not likely to lead to trouble—whether there ought not to be some limit put to it? The manufacturers said, if they were bound to produce cement of great strength and high specific gravity, it would cost them more to make it, and they argued that it was better to use a weaker cement with a less admixture of sand, than a stronger cement obtained at a greater cost with a larger admixture of sand. The heavy cement was obtained by hard burning; and when that was carried too far it was likely to cause the cement to fuse into a vitrified mass, which was of no use whatever. To prevent that it seemed there was an excess of chalk added, and if the chalk were not properly burned there was danger of that original defect of Portland cement, viz. that after it was thought to have been set it "blowed," from the lime not having been fully acted upon in the burning. Therefore it was well to see whether this 114 lbs. to the bushel was not as high a specific gravity as was required, and whether the 120 lbs. was a thing to be sought after; because he could understand that an Engineer, finding that the weight had been gradually raised from 110 lbs. to 112 lbs. and 114 lbs., and that 120 lbs. was attainable, might, in the desire to do the best, put into his specification cement of 115 lbs. to 120 lbs. weight per bushel, and by so doing might do harm instead of good. There could be no doubt that heavy cement set very slowly—not that at the end of a week it had not great tensile strength, but that at the end of an hour it was not in a condition to resist water so well as a lighter cement. He might say, in passing, with reference to the most desirable quality of cement for hydraulic works, that the material which was left behind out of the cement, after sifting through a sieve with 36 holes per linear inch, would not set at all. After several days it crumbled like sand; and he thought it would be well if chemists would determine whether that difficulty in setting arose from a difference in the constituents of the larger and harder particles, or merely from their having escaped the action of the millstones. He had found, even after pounding these particles fine enough to go through the sieve, that often, if they set at all, it was in a very poor manner.

The next point was as to the amount of water used in

gauging the cement for these experiments. He found, as a rule, that about one fourth-part by weight of water was the least quantity that would gauge the cement. If the cement were very quick-setting, or if it were very fine, it could not be gauged with so little water as that; that was the least that could be used with hard-burnt weighty cement. He had been curious to see what the effects would be of gauging with different quantities of water, and he found if only one-third weight of water were used, a sample would break at the end of ten days with 244 lbs., while if one-half the weight of water were used, the sample broke at the same period at 90 lbs.

Then he found that the resulting weight was nearly that of the mixed materials. Taking an equal weight of cement in all cases, viz. 30 oz., and mixing with 9½ oz. of water (which was the lowest quantity he could use), then with 10 oz. and then with 15 oz.; then pouring the mixture into square boxes, 2 inches square, the smaller amount of water gave a resulting bulk of a height of 8 inches, the next of 8½ inches, and with half water it gave a height of 10 inches. This showed that there was great temptation to use water largely, as it went to make bulk of the finished cement, although it was at the expense of its cohesive powers.

It had been stated in the Paper that it was important care should be taken as to the amount of water used in the gauging; but it had not been stated what proportions of water were used in the experiments. Mr. Bramwell might state that in his own experiments the specific gravity of the block made from cement mixed with half its weight of water was only 1·83 (that was taken at the end of four days), whilst the specific gravity of that mixed with only one-fourth weight of water was 2·25.

A suggestion had been made as to whether they were thoroughly acquainted with the different kinds of sand mixed with the cement when those two materials were allied together. In one of his experiments he took well-washed sand from the Thames, and in another some pounded Portland stone, the sand and the pounded stone being both sifted through the same sieve, and there was no doubt as to the superior strength of the cement block mixed with the pounded Portland stone; but he could not give the results with particularity, because a sufficient time had not elapsed to show the full effect, but it was

evident the Portland stone was considerably the stronger of the two. As regarded the way in which sand set with cement, it was desirable to know what changes took place after a block of this kind had set. He presumed, in the case of lime, that if they used lime alone they got very bad mortar, but that when mixed with sand it operated chemically upon the lime. The necessity for sand did not, however, exist with Portland cement, as that was strongest without any mixture of sand. It was a question whether the sand acted chemically, or merely as a means of filling up the spaces; if the latter were the case, he could understand that the larger grained the sand was, the better it was for the purpose, even irrespective of its being clean; for he believed with large particles they had less cubical contents of interstices than with small, as small particles did not lie much closer than large ones, so that the thickness of the interstices to be filled was nearly the same in both cases, while the area of the interstices was much greater in small particles than in large. A question had been raised with respect to cement placed in contact with iron, which turned out to be a question of cement upon oil. He might say, that having occasion to form a deck upon a floating dock, which deck he did not wish to be combustible, so as to be in danger if a hot rivet fell upon it, nor to be liable to rot if temporarily immersed in water in a tropical climate, and which therefore did not admit of the use either of creosoted or of unprotected timber, he had made every inquiry he could as to the behaviour of Portland cement concrete in contact with iron, and he was now having prepared a Portland cement deck 3 inches thick; but he was afraid that experiment would not settle the question at issue, because, after all, it would only be cement upon oil, all the iron having been steeped in oil when hot.

It had been suggested that there were great probabilities of cement with a large admixture of sand being used as a substitute for bricks. There was no doubt that good bricks had attained to an extraordinarily high price. From the Paper it appeared that the resistance to crushing of bricks, except the very best gault bricks, was 5 tons, while with proportions of one of cement to five of sand the resistance was on an average 12 tons. It was clear that in respect of crushing the cement bricks were far better than the ordinary run of bricks; so

much so, that he presumed it would be practicable to economize the material by making perforated bricks; but even if they were made solid, he calculated that at the present time they would cost 41*s.* 6*d.* per thousand. If the use of cement were still further economized, so as to bring down the power to resist compression at six months to that of ordinary bricks, there was some prospect of the cement brick being able to compete successfully with ordinary bricks.

Mr. J. B. Redman said he thought there was force in the remark that it was better to arrive at a high standard value for cement than to keep it down to that of the material to be attached. At the same time, it occurred to him that the value of the artificial material as evolved by these experiments, compared with some of the natural stones, gave a very high value to the former, and a very low value, in some cases, to the latter. Looking to the comparisons of Portland cement with Portland stone, the Author's tables gave the power of resisting crushing weight of the latter as only 167 tons per superficial foot, while Barlow gave a value of 294 tons per superficial foot. Some experiments were made two years ago by a Committee of the Royal Institute of British Architects, and in testing the relative merits of Ransome and Co.'s and M. Coignet's cements, and other materials, they found Portland stone gave a value of from 240 tons per superficial foot to 326 tons. It was clear therefore there was a wide difference between the observed results as to the value of Portland stone. As regarded the results brought out for the artificial material, Mr. Grant's experiments gave to the Portland cement a crushing power of 412 tons to the superficial foot, while Mr. White's Paper,[1] read some few years back, gave only from 146 tons to 160 tons, as shown by experiments made at the International Exhibition. This had relation to crushing power. It had been suggested that Roman cement might be usefully employed in tidal works in getting in deep foundations, and he might refer to a work which he carried out at East Greenwich twelve years back, in which a heavy river wall, subject to the tide twice a day, was put in without coffer-dams. That wall, which had been perfectly successful, was built in Roman cement, faced with rough

[1] *Vide* 'Minutes of Proceedings Inst. C.E.,' vol. xi. p. 478.

Guernsey pitching blocks, which had the property of resisting vegetation. A few years after that he built another wall, on the opposite side, in blue lias lime, on a base of concrete of blue lias lime, also without coffer-dams, and that was equally successful. He had also used concrete made with Roman cement in excluding the water at a great depth below low water, in a rapid tideway, in the bottoms of cylinder foundations.

Mr. J. F. Bateman, on the subject of hydraulic cements and mortars, would state the mode of construction adopted by Mr. Stoney for the Ballast Board at Dublin, for quay walls at that port. The ordinary quay walls were of concrete formed of one part of Portland cement to ten parts of the gravel of the Liffey. The crushing power at three months was 16 tons to the square foot, and this concrete was made at a cost of from 10*s.* 6*d.* to 10*s.* 8*d.* per cubic yard when set, exclusive of the cost of plant. It was not set in blocks, but was deposited between planks, in the ordinary way of making concrete walls. Owing to the success of those walls Mr. Stoney had undertaken the formation of concrete blocks on a larger scale than, he believed, had been hitherto attempted, in the building of a wall 24 feet below low water without coffer-dams. These blocks were made 23 feet upon the base, 26 feet deep, and 10 feet upon the face, weighing 330 tons each. They were built on a strong platform formed on the shore to carry this enormous weight, and were allowed to remain as long as was necessary to harden before they were removed. They were then floated to their destination, and lowered to the base previously prepared for them, under a large diving bell 20 feet square. The cost of these blocks, formed of one part of Portland cement to six parts of the gravel of the Liffey, and faced with granite, was estimated at 16*s.* per cubic yard exclusive of plant, and at 18*s.* with plant. In fine weather they might be laid on an average of one block at every tide; but by supposing that only one block could be laid every other day, or one hundred and fifty blocks in the course of the year, they would form a wall 1500 feet long, at a cost which was a mere bagatelle compared with other modes of construction involving the use of coffer-dams. It was about ten months since he investigated the question, and he could not report what had been done since. He could, however, speak with confidence as to the stability, strength, and apparent

durability of the walls already constructed—those in which the composition was one part of Portland cement to ten parts of the gravel of the Liffey.

Mr. R. P. Brereton said, doubts having been expressed as to the advantages of the use of Portland cement in water foundations, if passed through water either running or still, he would state that he had had opportunities of using it very largely under the latter condition. About seventeen years ago, when Portland cement was first thought of for foundations inside of cylinders, the late Mr. Brunel was employed in building a bridge across the Thames at Windsor. It was at that time stated that Portland cement answered well, used in the proportion of one part of cement to ten parts or twelve parts of gravel, and in that way formed an economical mode of filling up foundations in the water. In putting it in through water it was not considered prudent to try it in those proportions, but it was tried with one part of cement to nine parts of ballast. The cylinders were sunk through the gravel without pumping, and they became full of water through the bottom and under the sides. Through that water the concrete was passed, after being properly mixed, and it set hard and well in eight or ten days. The result of the first experiment was surprising. On pumping out the water there was on the top of the concrete a thin layer of slime and matter, which led to the expectation that the cement had been washed out of the concrete in its deposition, and for satisfaction on that point the concrete was carefully examined. It had set very hard, and on drilling nearly 3 feet into the concrete no amount of drilling, consistent with reason, could make any further impression. This proved that the slime was due to only a very small portion of the cement that had been washed out, and that the great bulk of it remained in the concrete; the proportions were afterwards increased to 1 to 6. The result of the experiment led to the use of that concrete very largely in subsequent bridges, and it was deposited in depths even of from 50 feet to 70 without the least attempt at pumping. When sufficient concrete had been deposited to balance the water pressure, and when, after ten days or a fortnight, it had set, the water was pumped out of the cylinders, and the remainder was filled in with concrete of the ordinary kind.

Those instances were sufficient to prove that concrete was good for all purposes so required of it. Those foundations, which had been built sixteen years or eighteen years, showed no symptoms of failure. With regard to the setting properties of this cement when used with sea sand or otherwise, he had found the use of sea sand and salt water perfectly satisfactory, both with Portland cement and lias lime; but there was no question as to its setting being rather retarded by that course. A few weeks ago, at some works in Wales on which he was engaged, in a tideway, he used cement mixed with sea sand and salt water, but it did not set quickly enough. He then tried the blown sand taken from the hills, not wet, and mixed with fresh water, and the cement set satisfactorily, whereas if the sand was saturated with salt water it took a longer time to set. In the case of lias mortar, so long as it was not subject to the wash of the sea it might be covered with water ten minutes after it was put in, and would set perfectly well, but not so quickly as if used in the dry state.

Mr. FOWLER, President, inquired whether, in passing the concrete through deep water, wooden spouts were used for the purpose? and whether Mr. Brereton's remarks, as to the comparative speed of setting of cements mixed with sea water and of those mixed with fresh water, had reference to works under water or above the surface?

Mr. BRERETON replied, that at Windsor, with a depth of 12 feet to 18 feet, the concrete was lowered in bags holding about 1¼ yard at a time, and it was discharged at the bottom. The same plan was adopted elsewhere in deeper water upon a larger scale, but a different disengaging apparatus was used. The result of his experience as regarded the speed of setting was, that the cement did not set fast enough before the tide rose when saturated sea sand and salt water were used. The work referred to was that of the invert of a dock entrance. It was put in when dry, but the tide rose before the cement had time to set; with the blown sand it set in half an hour.

Mr. JOHN COODE submitted that the average results given in the Author's tables, if taken without reference to the extreme results, were calculated to mislead. The Board of Works test was 500 lbs. on the briquette. Now 500 lbs. might be a mean or an average of 499 lbs. and 501 lbs., so would it be also a

mean of 1 lb. and 999 lbs. It would be desirable to ascertain what proportion of the cement of each maker had been below or above the required standard, and in what degree, so that the degree of superiority which the cement of one maker possessed over that of another might be known. There appeared to be an extraordinary range in the results, varying from 75 lbs. to 719 lbs. (Table II.) He thought it desirable also to have some experiments made on the relative strength of concrete formed with Portland cement and of that made with blue lias lime. (Table XLI.) He quite agreed that probably Portland cement would be used much more extensively than it was at present. Hitherto this cement had been rather dreaded. He was so satisfied with it that he had, some twelve months since, specified for the construction of a pier facing the German Ocean, and exposed to the " fetch " of a sea of from 190 miles to 200 miles, the whole of which, from the foundation courses upward, was to be of Portland cement concrete blocks, the face of the work, both seaward and towards the harbour, being of the same material, and he believed it would prove, both in point of strength and durability, to be equal to any ordinary building stone. In point of cost, it involved the question of building the pier in that material or not at all, for if the pier had been faced with stone, the expense would have been beyond the funds at the disposal of the authorities of the harbour in question. He was led in a great measure to adopt that material in the face of the work from having seen the result of the action of the sea upon a pier at Hartlepool. Some of the members might be aware that in the year 1856 a pier was projected in Hartlepool bay, which was stopped somewhat abruptly by Act of Parliament, and the work was left with the bare ends, both of the face-stones and concrete blocks in the hearting, stepped back in the ordinary way. He examined it after seven years' exposure to the action of the sea, and he found that the arrises of the Portland cement blocks—though they were not of first-class quality—were quite as sharp as those of the Bramley Fall stone with which the pier was faced. He had the authority of Mr. James May for saying, that the experience of more than fourteen years at Alderney had shown that the blocks of concrete made with Portland cement indurated with time rather than disintegrated. This seemed to be a reason for making

experiments upon the relative strength of concrete made with Portland cement and with different proportions of shingle and sand. He would also observe that amongst all the experiments made with that cement, he was not aware of any having been made with reference to its resistance to the action of attrition or abrasion. That was a quality which Portland cement possessed in a remarkable degree, and experiments in that direction might be worth the attention of manufacturers, and would, he anticipated, exhibit some extraordinary results, which would be very useful, and encourage the larger use of the material. Sea walls or piers faced with concrete blocks, and exposed to heavy seas, would not only have to resist the shock of the waves, but also the severe test of the attrition due to the moving sand and shingle, which were always found to tell considerably upon such works at the ground line in shallow water, and this was one of the greatest enemies to contend against in works so founded. In reference to the remarks upon the relative strength of test blocks when made with different descriptions of sand, it had been stated that in one experiment granulated Portland stone had been used as sand. The strength in that case depended upon mechanical adhesion, due to the porous and absorbent character of the material used as sand. Some years ago he had cemented together a pair of granite blocks, a pair of Portland Roach blocks, and a pair of blocks of ordinary Portland stone, all of the same sectional area, and he had found the relative amount of adhesion to be represented by 11 in the case of granite, 12 in the case of Portland Roach, and 16 in the case of the ordinary Portland stone—results which he believed to be simply in ratios corresponding to the porosity of the different stones.

His experience with Portland cement for works in an open tideway had not been altogether satisfactory, and he could not agree that it could be used for all purposes in a water-way. He first tried it about twelve years since, in attempting to set some large ashlar stones in a tideway at about 18 inches above low-water level. The blocks having been set, and a mere ripple—not to call it a wave—coming upon them, the cement was fairly pumped out of the joints. That, perhaps, was the strongest test to which a cement or mortar joint could be exposed, viz. the kind of pumping action which kept the whole

body ot cement in motion, and that action was more destructive in a straight ashlar joint than in rubble masonry. With regard to the export of Portland cement, the best and cheapest mode of conveyance on long voyages was by packing it in wrought-iron tanks, measuring about 4 feet each way as a convenient size, instead of in casks. Thus protected it always arrived at its destination in first-rate condition. He had on several occasions sent cement in that way to some harbour works he was executing without a contractor in South Africa. It resisted all moisture and damp on the voyage, whether from leakage of the vessel or any other cause, and the iron tanks had been sold in the colony generally for the same money, and in some cases even for more, than they had cost in this country.

Mr. Brereton explained that he had never used Portland cement concrete in a tideway; but in deep still water he had done so.

Mr. John Hawkshaw, Past-President, said he had used Portland cement in a tideway, and had not experienced any difficulty in so using it. Neither had he experienced difficulty in using concrete blocks in similar situations. In positions where the water was rough he took the precaution of immediately pointing the surface joints with Medina cement, which set very rapidly. As to the setting of concrete in water, he had passed it by means of boxes through 70 feet of water, and with the usual precautions it succeeded. In Italy he had seen sea walls built in 20 feet of water without passing the concrete to the bottom in boxes. Nothing more was done than to mark out the outline of the wall by piles boarded on the sides. It was mixed very rapidly, and a large number of men and boys were employed to carry it away in small quantities and throw it where it was to be deposited. Extensive sea walls were built in the Mediterranean in that way.

There could be no doubt that within his own experience the manufacture of Portland cement had been greatly improved, and it could now be relied on to an extent which could not have been done formerly. Therefore he could quite understand how the tests had been increased from time to time. He had so much confidence in it, that he was now commencing a large harbour on the Dutch coast, at the mouth of the Amsterdam sea canal, the piers of which were to be carried out a mile and

a quarter into the sea, and he proposed to build them of blocks of concrete made with shingle and Portland cement. He agreed that these blocks, when well made, appeared to retain their forms and preserve their surfaces equal to those of any stone which was used for these purposes.

With regard to the experiments where, by using a larger proportion of water, larger-sized cubes were obtained, he did not think they could be taken as a safe criterion, unless a considerable time was allowed for the concrete to dry. He did not gather that this had been the case; for there could be no doubt that cubes made of Portland cement and sand did go on improving for a considerable period. Some such cubes were in the room which had been made ten years ago, and they had evidently hardened with time, for he had lately made similar cubes and compared the two. Those he had made were of the finest sand (similar to that of the Dutch coast) and Portland cement, varying in proportions from 1 in 4 to 1 in 10. He believed blocks made in that way, could they be given time enough, would answer in some situations. The difficulty in using sand and cement arose from the fact that blocks so composed took a long time before they could be handled. The fact that no shingle was to be found on the coast of Holland had caused his attention to be directed to the use of sand alone for hearting or internal blocks. Since he had visited the Suez Canal he had been informed that there was some idea of making the piers at Port Saïd of blocks of sand and cement only, and no doubt, where there was time to wait till these blocks became hard, they would be suitable for portions of the work. Portland cement had the remarkable quality that it indurated to a higher extent in water than in air. That was in itself a great advantage in sea works. One thing which gave him confidence in adopting concrete blocks so extensively as he had done was what he noticed some years ago at ports on the Mediterranean. He endeavoured to ascertain the age of some concrete blocks which he saw in an old pier at one of those ports, not built, but thrown in as *pierre perdue*, and as far as he could make out, those blocks had been made about one hundred years. They were not perfect in form, but they had not been made with the care with which blocks were made at the present time for works of that kind.

As to how far Engineers should stop short of securing the best material they could get, of course that was a question which could not be solved by any specific resolution. If they had only a little money, they must make the most of it, and buy what materials they could afford. The Metropolitan Board of Works had plenty of money, and a large constituency to fall back upon, and they were not to blame for having tried to secure the best kind of work. The Author of the Paper had made numerous and careful experiments, and had presented them in a clear and lucid form; at the same time it would be a mistake to suppose that this was the first extensive use of this material, or that the experiments were very new. Many Engineers had used Portland cement for years, and many had made careful experiments with it. He agreed with the Author that weight was a test of quality, though that test alone could not be relied upon.

He had used lias lime extensively, and had found that when exposed to sea action and when mixed with pozzolana it sometimes softened to a very small extent upon its exposed surface. This fact would not be discovered unless the surface were examined minutely. In the interior of the work it would be quite hard, but where it was exposed to the sea a thin film would be found softened by the sea water; he had not yet observed that Portland cement was so affected; whether it was in consequence of using pozzolana he could not say. With regard to pozzolana, it was, he thought, in many cases a mistake to apply it to hydraulic limes. It was much esteemed by the old Engineers, who knew that the Romans used it to a great extent, and their works were regarded as being of a very enduring character. He had taken the pains to examine almost every important work in Italy. He had seen most of the aqueducts, and he found that pozzolana was always used; but the Italians mixed it with common white lime, and with that lime it made a good mortar; but he was inclined to believe the combination of pozzolana with hydraulic or lias limes was not in every case beneficial; and it would be better, where good lias lime was to be had, to leave out the pozzolana.

Mr. E. Druce referred to the specimens which showed the results of Portland cement mixed with different proportions of sand up to 1 to 10. These specimens were mixed by himself just

ten years ago, and were, he thought, of special interest, as showing the cement in its ultimate state of hardness. There was also a piece of a Portland cement block, which bore upon the point alluded to as to the abrasion of a Portland cement concrete by shingle, it having formed, during a period of six years, the outer corner of a sea-shore groyne on the coast of Sussex, round which very large quantities of shingle had been constantly passing. It was part of an ordinary Portland cement concrete block, made in the proportions of one part of cement to nine parts of shingle and sand. The abrasion had been very slight, and the cement had shown no signs of weakness, nor had any stones been displaced. He would now direct attention to the appeal of the cement manufacturers in behalf of light cement as against heavy, or more highly manufactured cement, the statement being that cement of 104 lbs. to the bushel was, for all practical purposes, as good as that of 114 lbs., and a table of results was brought forward in proof of that assertion; but the comparison, as made in the table exhibited, was between 104 lbs. and 112 lbs., and not between 104 lbs. and 123 lbs., which latter was the subject of the table prepared by the Author, and with which the results obtained from the light cement bore no comparison. The latter was the class of cement that was used in the works at Dover, the average of the cement employed there being 124 lbs. to the bushel. It was further to be remarked that the comparison in Mr. White's table was between cements of only thirty days old, and it was no doubt wished that the inference should be drawn that the ultimate strength would follow in the same proportion. He apprehended that it was the ultimate strength of cement, and not that at its earlier or intermediate stages, which concerned Engineers. A comparison, however, of the properties of these cements would explain how this apparent equality in results had been obtained, and also why the heavier would give an ultimate result far better than the lighter quality. The light cement of 104 lbs. had the property of quick setting, and showed good results in the first instance, but it arrived at its state of ultimate hardness at a comparatively early period; while the heavier cements showed moderate results at the earlier stages, but continued the process of hardening at a rate much more in proportion to their age; the period for arriving at their ultimate hardness being also much longer, as shown by the

Author's table, which stated it to be from one year to two years. The results of four hundred experiments made by himself on each of these classes of cement satisfactorily proved the superiority of the heavy cement, and that the inference sought to be established was entirely fallacious. These results had been fully borne out in practice on the works at Dover by the quality of the concrete blocks and in other ways, and the contractors were so satisfied that it was to their own interest to use heavy cement that they now declined to receive any but that above named. They had lately executed a most important work, which was one of the large detached forts in the deep water of Plymouth Sound; and from using only the highly manufactured cement they had lost but three blocks during the whole time of the contract. He considered the requirements of the French Engineers were below the standard of what Portland cement should be; but they used it in a peculiar way. They mixed Portland cement with Medina cement, which was much quicker in setting than the Portland, and the union of the two materials might possibly result more satisfactorily when their rates of setting were more nearly alike. It had been asked, What was the use of having a cementing material of greater strength than the materials which were to be joined together? To that inquiry the general answer might be given that there was no use; but at the same time it did not follow that such a result would attend the use of heavy instead of light cements. The strength of cement might be reduced to any extent that was desired, and economically so, by increasing the proportions of sand employed; and as for a long time past the price of heavy and light cements in the market had been much the same, there was a considerable saving in using the heavy cement with the larger proportion of sand that it would take. At the same time it must be admitted that greater weight meant nothing less than higher manufacture, and that heavy cement was worth a higher price. The natural conclusion was that the light cement, from the great demand for it, was commanding a higher price than it deserved. The difficulty with Portland cement now was that it could not be depended upon. If a sudden break in a sea wall occurred Medina cement could be used with the certainty of good results; but with Portland cement it was almost a matter of necessity that it should

undergo a course of tedious tests before assurance could be obtained that the cement would not "blow" in the work, and this bar to its use would remain until the makers adopted the course pursued in other manufactures, which was, to aim at every possible improvement in quality, with the certainty of a good article always commanding its value in the market.

Sir Charles Hartley said, in connection with the employment of cement and pozzolana abroad, that he could give a brief account of certain works he had inspected during the last month on the French and on the Italian coasts. Harbours of refuge were being constructed at Biarritz and at St. Jean de Luz, situated on the rocky seaboard between the mouths of the Adour and the Bidassoa, and consequently at the very head of the Bay of Biscay, a position peculiarly exposed to the fury of Atlantic gales from the N.W. The rise and fall of the tide at this part of the coast varied from 3 mètres to 5 mètres. At Biarritz the works were carried on under great difficulties, owing to its being without a safe haven for the shelter of small craft, to the number of detached rocks, to the great depth of the sea close in-shore, and to the presence of an almost incessant ground swell even at times of perfect calm. This unfavourable condition of things obliged M. Daguenet, the Engineer in charge, to advance the new jetty from the mainland to its full height at once by pitching large blocks of béton into the sea from a temporary waggon road. Many of the blocks were broken and the work often breached by the adoption of this plan; but such mishaps were difficult to avoid, as there was no possibility of conveying the blocks by water. The blocks used had a cube of 33 tons each, and were composed of Portland cement, stone, and sand, in the proportions of 1 part of cement to 2 parts of sand and 3 parts of broken stones. After being made they were allowed to remain for three months to harden, and were then conveyed in waggons to the tip-head.

At St. Jean de Luz the proximity of a small tidal harbour rendered the formation of a new jetty[1] a much easier task, for under its shelter blocks were made on the shore, between high-

[1] This work, like the Biarritz jetty, is intended to have a length of about 300 mètres, founded at an average depth of 24 feet below low-water mark.—C. H.

water and low-water mark, and from one month to two months afterwards, according to the season, were taken to the jetty by a couple of pontoons, and quietly lowered into place. The blocks measured 4 mètres by $2\frac{1}{2}$ mètres and 2 mètres on their sides, and weighed 44 tons. They were begun and completely finished during the ebb of a single tide, and the boards which then encased them were removed within twenty-four hours afterwards. The proportions of these blocks were 1 of Portland cement, $2\frac{1}{2}$ of sand, and 3 of stones. They set much sooner and supported more sand than the Biarritz blocks, in consequence of their frequent immersion in water immediately after being built; and they were not liable to fracture when deposited, on account of the employment of pontoons. The jetty above the level of ordinary low water was entirely constructed of very small rubble—faced with ashlar rarely more than 3 feet cube—set in Roman cement, or rather in the quick-setting Spanish cement, which very nearly resembled it, and which, after being used half an hour, was capable of resisting the heaviest seas. This appeared to be a skilful application of two cements differing widely in their respective qualities, and however much the durability of a very quick-setting cement might be questioned, its success in the meantime at St. Jean de Luz, where it was employed under trying circumstances, was undoubted.

At Genoa a pier was being carried out in a depth of 42 feet, and was advancing at the rate of 50 mètres annually. Its width at the water-line was about 120 feet; its sea-slope stood at 2 to 1; and its inner slope at $1\frac{1}{2}$ to 1. The body of the work consisted of small rubble and quarry rubbish, the outer coating, next the sea, of natural blocks of limestone from 5 tons to 90 tons in weight, and the inner slope of first and second class rubble. From the water-line to 4 feet below it the whole width of the pier was covered with a layer of béton built *in situ*, and the interior quay wall, which had a thickness of 18 feet, and was built of the same material, was founded at a depth of 9 feet by means of a temporary casing of 3-inch sheet piling, supported by timber walings and stout iron upright bars fixed in the rubble. The béton thus so extensively used consisted of 1 part of rich lime, 2 parts of pozzolana, and 3 of broken stones; and so well had it answered that along the line of the finished pier not the slightest sign of settlement could be detected. Above

the water-line blocks of 12 mètres cube were built in place, some of them consisting of Italian cement, sand, and shingle, in the proportions of 1, 2, and 3 respectively, and others of mortar, of the same quality and proportions, and third-class rubble.

At Spezzia pozzolana was used exclusively for the dock walls, where they were set dry, in the proportions of 2 parts of pozzolana to 1 part of lime and 3 parts of stones; but for the quays, built in the water in the manner described by Mr. Hawkshaw, the cement of the country was used in the proportion of 1 part of cement, 2 parts of sand, and 3 parts of broken stone.

At Leghorn a noble breakwater 1040 mètres long, and built in a depth of 30 feet, was on the eve of completion. With the exception of the interior quay wall and the parapet, it consisted entirely of béton blocks, and so well had the blocks, built on shore, been placed by means of pontoons, that the outer as well as the inner slope stood immovable at an angle of 45°. The submerged blocks of 10 mètres cube consisted of 0·70 of lime, 0·42 of sand, and 0·42 of pozzolana; and the still larger blocks built in place above water consisted of third-class rubble, and mortar made of 0·70 of lime and 0·84 of pozzolana.[1]

With regard to the relative value of cement and pozzolana, he might state that Italian Engineers, as a general rule, preferred the latter, principally on the ground that it had stood the test of centuries, whereas they contended that cement for sea work was still on its trial. They argued, moreover, that béton formed of pozzolana was infinitely cheaper in Italy than béton composed of the cements of France or of England; and in support of this assertion they might have quoted the fact that pozzolana blocks only cost from 20 francs to 28 francs a cubic mètre, at almost any part of the Italian seaboard, whilst a wall built at Genoa with the Valentine cement of France had cost 45 francs; the blocks used at Biarritz, and made of

[1] At Leghorn and Spezzia pozzolana will only be received from a certain locality in the neighbourhood of Rome, where its peculiar colour is unmistakable; and in order to test the actual quantity delivered it is held that a cubic mètre of this pozzolana weighs 1195 kilogrammes. On reaching the works therefore it is measured and not weighed (so that there may be no temptation to water it), and payment is made at so much per ton—generally 17 francs delivered—by assuming that 10 cubic mètres weigh 12 tons.—C. H.

Portland cement, 40 francs; and the Cherbourg blocks, made also of Portland, as much as 55 francs per cubic mètre—the cost of materials, labour, and immersion being included in each case.

The choice of a cement, or of pozzolana as a substitute for it, depended so much on the character of the work to be executed, and on its geographical position, that the greatest merit would ever be due to those who selected the materials of construction best adapted to the exigencies of the situation. Thus it might be found that pozzolana was superior to cement where, as in Italy, the former was plentiful and cheap and the latter scarce and dear; that Portland cement was more suitable than pozzolana wherever there was a constant wash of the sea to contend with, or where, as at Biarritz, great tenacity was required; and that a very quick-setting cement was best where, as at St. Jean de Luz, the construction of a temporary cofferdam or casing was impossible.

He believed, as a rule, foreign Engineers were bolder in their concrete works than English Engineers had been hitherto; and he fully agreed with those who predicted a much larger use of English cements, and especially of Portland cement.

Mr. T. D. Ridley wished to draw the Author's attention to the mode of applying the tests. At the Thames Embankment works, when a bargeload of cement arrived, an officer appointed by the Board of Works inspected it, and from each tenth bag a sample was taken, which was made into blocks and then tested. In these tests it was almost invariably found, certainly in more than ninety cases out of one hundred, that the fracture took place at the junction of the small part of the section with the large, and in a curved form. He therefore inferred that the fracture was due, to a certain extent, to transverse, and not altogether to tensile, strain. If such were the case it would detract from the correctness of the results arrived at in these experiments, and it might be desirable to devise a means of suspending the block, so that the strain should be entirely tensile. He wished to add his meed of praise for the assiduous care bestowed in the testing of these cements, which had, no doubt, greatly contributed to the improved manufacture of cement.

Mr. John Grant, in reply, said he wished to notice the principal exceptions that had been taken to the tests he had

ventured to establish. A formidable list of the objections to a very heavy specific gravity and high quality of cement had been made out, and he had arranged those objections in the following order:—First, loss of quantity produced from a given amount of material. Second, loss of fuel in extra burning. Third, wearing out of the kilns. Fourth, wearing out of the millstones. Fifth, impossibility of getting the whole of the calcined results of the materials of the same quality. Sixth, no increase of price to the manufacturers. Seventh, the dangerous character of this high quality of cement. Eighth, its slow-setting character, under certain circumstances. Ninth, its liability to inferior grinding.

With regard to the first six objections, he thought they might be dismissed as being entirely questions for the manufacturer. He would confine himself therefore to the two which were raised in an engineering point of view, and chiefly to the point that cement of this high specific gravity was dangerous. The best answer he could give was the experience which had been obtained in using between three and four millions of bushels during the last six or seven years in the Main Drainage works of London. Those works had been seen by a large number of the Members of this Institution; and he felt assured that if those works were critically examined no proofs of this cement being dangerous could possibly be discovered. Any such instance of the cement being dangerous was utterly unknown to him, either in the works on the south or on the north side of the river.

As to specific gravity, a table was exhibited by an eminent manufacturer, of which, after the careful examination it had received, it was unnecessary for him to say more than that as far as regarded the experiments on the cements used on the Main Drainage works, three out of the four lines composing that Table were inaccurate.

Table XXXIX. in the Appendix, showing the tensile strains of cements of different specific gravities at different periods, was a summary of four preceding Tables. From this it would be perceived that cement weighing 109 lbs. per bushel bore a tensile strain at the end of a week of 767 lbs., at the end of a month of 886 lbs., and at the end of a year of 1099 lbs.; cement of 112 lbs. (two lines) bore 558 lbs. and 445 lbs. at the end of a

week, 784 lbs. and 680 lbs. at the end of a month, and 1010 lbs. and 1075 lbs. at the end of a year; but when it weighed 123 lbs., which was the quality of cement used by Mr. Druce at Dover, a marked difference was visible, as then at the end of a week it bore 817 lbs., at the end of a month, 936 lbs., and at the end of a year, 1230 lbs., considerably higher than those of any of the lighter cements. But there was still stronger proof, and proof which had the advantage of being taken from the ordinary daily records, made without the slightest view of illustrating this point. In those records, which were kept on every contract under the Metropolitan Board of Works, an entry was made of the weight per bushel of every load of cement brought in. He had taken from one of these records kept at the outfall works at Crossness, the result of 327,000 bushels of cement used there during two years. In Table XL. were shown the results of the tensile strain of cement varying from 106 lbs., 107 lbs., and 108 lbs. per bushel up to 130 lbs.; beginning at 106 lbs., with a tensile strain of 472 lbs., and finishing at 130 lbs., with a tensile strain of 914 lbs. This Table, as was evident, had not been prepared in any way to illustrate this point, for there were several discrepancies in it, and several results that would seem to be unfavourable to the argument he was maintaining; but he had given it in its integrity, and the main lesson which that Table taught was, that weight legitimately obtained by burning meant strength. It was true that there might be weight without strength; it might be got improperly; but he said, in the presence of many large manufacturers of cement, most of whom, he was certain, agreed with him, that weight meant strength.

Only that day additional confirmatory proof had been obtained on this point. On the Embankment works, on the north side of the river, one maker supplied 1600 bushels. These were tested by eighty tests; the weight of the cement per bushel was found to be 113 lbs. and the tensile strain at the end of a week was 596 lbs. Another maker supplied 1000 bushels, which were tested by fifty tests; the weight per bushel was 117 lbs., the tensile strain 655 lbs. In another case 1500 bushels of cement of 121 lbs. were tested by seventy-five tests; and the tensile strain was more than 790 lbs. Four of those tests broke between 465 lbs. and 650 lbs.; but seventy-one out

of the seventy-five tests went to the full extent of the instrument, which was 790 lbs., and the cement was not broken at that strain. He had been asked to explain how he came to adopt these tests. He had been challenged on that point, otherwise he had not intended to refer to it. In 1858–9, when he commenced these experiments, he sent to some of the principal manufacturers for samples. He tested these carefully, and made numerous experiments, and found that the manufacturer who had advanced the objection to specific weight furnished the heaviest of those samples, which also proved to be the strongest cement of all. When he ascertained that it was intended to put such high tests into the specification as 110 lbs. weight per bushel, and 400 lbs. tensile strain at the end of a week, he objected that 400 lbs. was much too high a test in practice. In reply, that maker's own particular cement was pointed out, which showed a result 40 per cent. higher than was specified. The Author was then told candidly that he must not take these results and expect to get cement in any quantity equal to the sample of cement which had been sent in, as it had been prepared specially for the purpose. In fact no other specimen came within 10 per cent. of that sample, and due allowance had been made for this circumstance, as would be seen by a tensile strength of only 60 per cent. having been fixed upon. The weight of 110 lbs. and tensile strain of 400 lbs. were, after full consideration, maintained.

A remark had been made, to the effect that he had gone too far in insisting upon such high tests; but it would be seen that all due caution had been exercised, when it was considered that those tests had been continued for three years, and that it was only after using nearly a million of bushels, averaging 114 lbs. per bushel, and a breaking weight of 607 lbs., that 2 lbs. were added to the weight per bushel, and 100 lbs. to the tensile strain on the 2¼ square inches sectional area. Experience had fully confirmed the moderation of these requirements. Instead of 110 lbs., the average specific weight of 114 lbs. per bushel had been realized; and instead of 400 lbs. tensile strain, 607 lbs. had been attained, the quantity used on the south of the Thames having been about one and a half million bushels. There had been thus no cause to regret the adoption of so high a standard, either from danger to the works or from any other cause.

While on the question of tensile strain, it might be as well to refer to a point which had been raised by Mr. Coode as to averages, that there might be a high average through very great extremes. He was happy to state, in general terms, that the minimum had exceeded the specified standard, the maximum being very large indeed, upwards of 1000 lbs. at seven days, and the average 50 per cent. above the original standard. To show how important the specific gravity of Portland cement seemed to the manufacturer he might cite the following fact:—Mr. William Lee, M.P., who was surety for a contractor who failed, had to carry out the Southern High-Level Sewer, and was responsible for the strength and soundness of the work. This work he did very well. Mr. Lee manufactured his own cement, but instead of contenting himself with sending cement of 110 lbs. per bushel, breaking at 400 lbs., which was the requirement, he sent in cement of 120 lbs. to the bushel, and a breaking weight of 680 lbs. tensile strain, being 70 per cent. above proof strength. But there was one point which seemed to have been overlooked by the objector to a very high quality—viz. the interest of the purchaser, who, if a contractor, was responsible for the soundness of the work; or, if an Engineer, was staking his credit and good name on the character of the work executed with the cement. This point was of greater importance than the difference of price between cements of first and of second rate qualities.

It had been suggested that Portland cement might pass those tests of weight per bushel, tensile strain, and even the water test, and yet afterwards prove to be dangerous. Such a result was quite impossible. It might pass the weight per bushel; it might, for a short time, pass the test of tensile strain: but it could not pass the test of water. This brought him to the question of what should be done in cases of emergency, in order to ascertain the character of the cement. In such cases the tests of specific gravity and tensile strain might be laid aside, and the water test alone be applied. A very short experience would enable anyone to ascertain whether a cement was safe, strong, or weak. When it was necessary to know the character of cement without loss of time two pats were made of it. One was put into water and the other was kept dry. By the colour alone it was obvious whether there was an undue preponderance

of clay. If there was, the cake which was put into water would assume a buff colour. If it had been overchalked, or overburnt to the point of danger, little cracks would be perceptible all round the edge in the wet cake; and if the latter of these indications was found, the cement must be laid aside, and it must be ascertained whether it had merely been supplied too new and hot, or was really so improperly manufactured as to be unfit for use.

A question had been asked as to the relative cost of lias lime mortar of first quality, and Portland cement compo or mortar. First-class mortar at the Liverpool docks had been stated to have cost from 9*s.* per cubic yard to 10*s.* per cubic yard. In Mr. Robertson's Paper on Hydraulic Mortar used at the London Docks,[1] it was stated that the net cost of the first quality of mortar at the works was 14*s.* 3¾*d.* per yard of one kind, and 12*s.* 9*d.* for another. He had endeavoured to ascertain the cost of Portland cement mortar, or compo, mixed in different proportions. In the proportion of 1 to 1 the cost was about 25*s.* per cubic yard, in the proportion of 2 to 1, 18*s.* 3*d.*, of 3 to 1, 15*s.*, of 4 to 1, 13*s.*, and of 5 to 1, 11*s.* 6*d.* per cubic yard. The sand and cement seemed to lose about one-sixth of their bulk when made into compo, and another sixth in setting—altogether about one-third of the original bulk of the sand and cement. It had also been asked whether the cement could be regauged? He did not think it could; and he did not think it desirable that Portland cement should be allowed to stand very long after being gauged before it was used, inasmuch as the process of setting or crystallization appeared to commence immediately after it was wet. If disturbed after one hour or two hours it lost much of its strength. The gauging was always done in moderate quantities with a shovel upon a mortar board.

Portland cement blocks for facing sea walls might be made of extra strength and density by increasing the proportion of cement; and (when not of too large size) by compressing the materials in iron moulds or boxes and using the smallest quantity of water. Some excellent specimens of artificial stone, made in this way some years ago at East Greenwich, might be seen in front of the Terrace, Lewisham, Kent.

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[1] *Vide* 'Minutes of Proceedings Inst. C.E.,' vol. xvii. p. 410.

He would add some Tables of experiments made to illustrate the principal points raised in the discussion (Tables XXXVI. and following Tables); and would say generally with regard to these experiments, about fifteen thousand in number, that they had been made with all integrity upon the cements used in the works, and made by different manufacturers. He had not compared his results with those of anyone else; he had given them exactly as they transpired. If these experiments, made for practical purposes, had not been given to this Institution, they would have been buried in the records of the office, and perhaps never been published. He had started with no theory of his own; he had none to establish: moreover, his own knowledge of the subject was at first very slight. What he had ascertained was by experience from day to day during a period of seven years. He had previously used Portland cement only on a small scale and in running water, where it was apt to leave the joints, and he had not persevered with it to the extent he had since. But having been called on to take part in carrying out the Main Drainage works, it seemed to him to be of the greatest importance to get cement which could be thoroughly depended upon, in works carried through ground so full of water that the pumping in many cases came to 10 per cent. of the whole cost.

Mr. Fowler, President, said this was one of the most able and useful Papers that had come before the Institution for a long time. But it occurred to him, as no doubt it had to several others, that this Paper would be still more valuable and useful if it were supplemented by another on blue lias and greystone lime mortars, so that comparisons could be made between the results of experiments upon mortars and the results of the experiments made upon Portland cement; and he hoped that from the Author, or from some other Member, such a Paper would be forthcoming, either in the present or in the next session of the Institution. It was almost impossible to arrive at the true value of such a material as Portland cement, excepting by comparison with other cements or mortars used by Engineers for the same purposes. He trusted that if the subject was undertaken it would be with the same care as that bestowed upon the experiments upon Portland cement, and that the experiments would be continued for the same period. If

another Paper on mortars could be equally well prepared, and the discussion upon it be equally well sustained, this Institution would have on that subject confirmation of the most valuable kind—valuable, he might say, to experienced Members as well as to young Members; because he thought there was not a single Member, whatever his experience had been, who had not derived some new information and some new knowledge from the present Paper and the discussion that had taken place upon it.

FURTHER EXPERIMENTS ON THE STRENGTH OF PORTLAND CEMENT.[1]

In a previous Paper, Session 1865–6,[1] the Author stated that "further experiments were desirable on the strength of adhesion between bricks and cement under varying circumstances; on the limit to the increase of strength with age; on the relative strength of concrete made with various proportions of cement and ballast," &c. The experiments described in this communication have been tried with the view of throwing some additional light upon these points; and though no one can feel more than the Author their fragmentary and incomplete character, he has, after long hesitation, decided to lay them before the Institution. If they serve no other purpose, their incompleteness may point out to those who are interested in the subject, and have time for further investigation, the direction which their inquiries might advantageously take, and the large field yet open for their labours.

Before describing the new series of experiments it may be useful to review some of the points in the previous Paper. Among these was "the limit to the increase of strength with age." Tables XVIII. XXIV. XXV. and XXIX. were intended to illustrate this point, and the five years which have since elapsed have to some extent afforded the desired opportunity.

Thus in Table XVIII. were given the results of one hundred and sixty out of three hundred experiments intended to extend over ten years, and made with Portland cement weighing 123 lbs. to the imperial bushel. It was shown that neat cement which at seven days broke at 817·1 lbs. increased

[1] *Vide* 'Minutes of Proceedings Inst. C.E.,' vol. xxv. p. 79.

gradually in strength till at two years it bore a tensile strain of 1324·9 lbs., and at three years of 1314·4 lbs., or practically the same. By the extended Table in the Appendix it will be perceived that the maximum was attained at two years, the further results being 1312·6 lbs., 1306 lbs., 1308 lbs., and 1327·3 lbs. at four, five, six, and seven years respectively. With cement and sand in equal proportions the tendency to increase in strength continued; that which at seven days broke at 353·2 lbs., or 42 per cent. of neat cement; at one month at 452·5 lbs., or nearly 50 per cent. of neat cement; at two years at 790·3 lbs., or 60 per cent. of neat cement; bore strains of 818·1 lbs., 821 lbs., 819·5 lbs., and 863·6 lbs., at four, five, six, and seven years respectively. The results at four, five, and six years were practically the same, being 62·6 per cent. of neat cement, and at seven years 65 per cent.

Table XXIV. gives the strength of Roman cement at various stages from seven days to seven years. The results do not uniformly and regularly increase. It was shown that this cement bore a strain of 201·83 lbs. at seven days, of 376·8 lbs. at six months, and of 323·8 lbs. at twelve months. The further experiments give the following results: 438 lbs., 450·8 lbs., 512·6 lbs., 466·9 lbs., 466·6 lbs., and 553·2 lbs., at two, three, four, five, six, and seven years respectively. The differences between the minimum and the maximum are very great, and confirm the conclusion that this kind of cement is not nearly so uniform in strength as Portland cement, and that though about two-thirds of the price it is only about one-third of the strength, and therefore double the cost of Portland cement measured by strength.

Table XXV. relates to another Roman cement, and brings down the experiments six years later. Cement which at seven days broke with a tensile strain of 202 lbs., and attained to its maximum 643·1 lbs. at twelve months, broke at 546·3 lbs., 603·8 lbs., 632·2 lbs., 627·4 lbs., 666·4 lbs., and 708·7 lbs., at two, three, four, five, six, and seven years respectively.

Table XXIX. refers to Medina cement, which at seven days bore strains of 92·1 lbs. (1st series), and 211 lbs. (2nd series), attained a maximum strength of 476·9 lbs. at twelve months, and bore only 276 lbs. at two years. At three, four, five, six, and seven years the strains were 275·5 lbs., 287·8 lbs., 307 lbs.,

365 lbs., and 377·5 lbs., respectively. This series of experiments is to be continued to eight, nine, and ten years.

As a preliminary to the further experiments hereafter described, upwards of two hundred were made to ascertain if any improvement could be devised in the form of mould previously used. The results of these are given in Table I. of Appendix. Form No. 1 is that which was adopted at first (January, 1859), because it was found in use both in France and in England. Form No. 2 shows the same mould with the inner angles rounded off. In Form No. 3 the outer angles and shoulders were also rounded off. This form and the other shapes which follow were found to have a tendency to slip in the clips when under tension. Forms Nos. 4, 5, and 6 were like dowels of different lengths, but with the same sectional area at the neck as the preceding, viz. $1\frac{1}{2}$ inch by $1\frac{1}{2}$ inch $= 2\frac{1}{4}$ square inches. Forms Nos. 7, 8, and 9 were like the three preceding, but with a breaking area of 2 inches by 2 inches = 4 square inches. Form No. 10 is that shown on Plate 3 of the original Paper, and has the same area as Forms Nos. 7, 8, and 9. Twenty moulds were made of each kind: ten were broken at seven days, and ten at thirty days, all having been kept in water. Forms 2 and 3 gave the highest and almost identical results. It was therefore presumed that No. 2, which is the form of mould shown in Plate 4 of the original Paper, was of all the least subject to error and irregularity; and this form has been used in the tests and experiments described in this Paper, except where otherwise stated, and is the standard constantly employed by the officers of the Metropolitan Board of Works. Perhaps the lower results given by the moulds Nos. 4–9 were due to the wedge-shaped ends opening the breaking clips when the strain was applied. The later investigations of Mr. Bramwell, "On the Influence of Form on Strength"[1] would lead to the preference of this form to those marked Nos. 1, 2, 3, or 10. Further experiments are being made on this point, and means taken to prevent the clips from opening.

On another point a large number of experiments were made, viz. as to the best mode of avoiding any distortion or departure from the line of strain. The plan originally adopted is shown

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[1] *Vide* 'Report of British Association, 1869,' p. 422.

on Plate 2, and a modification on Plate 4, of the former Paper. It was found, however, that the altered moulds frequently broke at the holes in each end of the specimen instead of at the neck. The original clips were therefore reverted to, but in combination with knife-edges in the eye and pin at each end.

The next step was to establish the conditions to be observed in the following new series of experiments:—

A. On the strength of Portland cement tested by tensile strain at different periods, from one day to twelve months.

B. On the adhesion between bricks cemented with Portland cement and lime mortars, tested by tensile strain at the end of twelve months.

C. On the strength of Portland cement bricks, neat, and with different proportions of sand, tested at the end of twelve months by compression in a hydraulic press.

D. On concrete blocks of different proportions of Portland cement and lime, with gravel, sand, and other materials, tested at the end of twelve months by compression.

For the purpose of these experiments the directions given were:—

"Take about 40 bushels of Portland cement weighing not less than 112 lbs. per bushel; sift the whole of it through a sieve with twenty holes to the lineal inch.

"Note the proportionate quantity which will not pass through this sieve. Fill each bushel measure from a movable hopper placed at an uniform height of 2 feet above the mouth of the measure, and weigh each 'striked' bushel. Afterwards put the whole quantity together and turn it over many times to ensure the thorough admixture of the cement. Use the same cement for the several varieties of experiments.

"Ascertain the quantity of cement required to fill a mould, and the quantity of water required to bring the cement to the consistency of paste.

"In filling a mould with neat cement, use always the same proportion (by weight) of cement and of water.

"Get 40 bushels of clean sharp sand, wash and afterwards dry it; take the weight per bushel, and in making tests with different proportions of cement and sand weigh the proportions of each—thus, to ensure equal quantities of Portland cement

and sand, take, say one-fiftieth part of a bushel of cement (by weight) and one-fiftieth part of a bushel of sand (by weight), and mix the two together for an experiment of 1 to 1.

"Use scales and weights, the latter adapted to show decimal parts of a lb. instead of ounces.

EXPERIMENTS. Series A.

"On the strength of Portland cement tested by tensile strain at different periods, and with different proportions of sand. Kept in water.

Time in Moulds. Ten Moulds each.	Mixed by hand.	Ground in a Mortar-Mill for Thirty Minutes.
	Broke at lbs.	Broke at lbs.
1 day	"	"
2 days	"	"
3 "	"	"
4 "	"	"
5 "	"	"
6 "	"	"
7 "	"	"
1 month ..	"	"
2 months ..	"	"
3 "	"	"
4 "	"	"
5 "	"	"
6 "	"	"
7 "	"	"
8 "	"	"
9 "	"	"
10 "	"	"
11 "	"	"
12 "	"	"
	Total, 190 moulds.	Total, 190 moulds.

Series B.

Kinds of Bricks to be used.

1. Gault clay. Pressed.
2. Do. Wire cut.
3. Do. Perforated.
4. Suffolk (brimstones).
5. Picked stocks or shippers.
6. Farnham red.
7. Blue Staffordshire, pressed, with frog.
8. Do. do. rough, without frog.

"Before using the bricks:—

"1st. Take their dimensions in inches and tenths; give area of bed, area of edge, and cubic contents.

"2nd. Weight—dry.

"3rd. Do. after being soaked twenty-four hours.

"4th. Strength by compression in a hydraulic press.

"Put together blocks, each composed of four bricks, making the joints one-fourth of an inch thick, viz.:—

i.	10 of the gault clay, pressed, with neat cement.			
ii.	"	with Portland cement and sand		1 to 1
iii.	"	"	"	1 to 2
iv.	"	"	"	1 to 3
v.	"	"	"	1 to 4
vi.	"	"	"	1 to 5

vii. 10 with lias lime (specially burnt and ground forty minutes in an edge-stone mortar-mill) and sand, in the proportion of 1 to 2.

viii. 10 with ground Dorking lime-mortar.

ix. 10 with chalk lime-mortar.

"Make the same number of blocks of each of the other kinds of bricks.

Series C.

"Make—

10 Bricks (9 in. by $4\frac{1}{2}$ in. by 3 in.) of Portland cement neat.			
"	"	Portland cement and sand	1 to 1
"	"	"	1 to 2
"	"	"	1 to 3
"	"	"	1 to 4
"	"	"	1 to 5
"	"	"	1 to 6
"	"	"	1 to 7
"	"	"	1 to 8
"	"	"	1 to 9
"	"	"	1 to 10

"Put half of each kind in water and keep the other half out of water; test at end of twelve months by compression.

"Take weight dry, and same wet.

"Make a similar series of cement bricks, compressing them in moulds either by hydraulic press or by ramming, and test as above.

SERIES D.

"Concrete blocks, 12 inches by 12 inches by 12 inches, and 6 inches by 6 inches by 6 inches. To be tested at end of twelve months.

"One of each to be kept in the open air, and one immersed in water all the time.

4 to be made of	1 cement to	1	ballast.
"	"	2	"
"	"	3	"
"	"	4	"
"	"	5	"
"	"	6	"
"	"	7	"
"	"	8	"
"	"	9	"
"	"	10	"

"Make two of those above by compressing the materials in layers of 1 inch thick, either by rammers or in a hydraulic press.

"After setting, put one of each in water as before. Note the quantity and weight of the materials composing the two kinds of blocks.

"Make—

4 of	Portland cement to	6	ground pottery.
"	"	8	"
"	"	10	"

"One of each to be kept in air, and one immersed in water. Two of each kind to be formed by compressing the materials as before.

"Make twelve more of same proportions, using ground slag.

"Make twelve more of ground bottle glass.

"Make twelve of ground flints; the chalk on the surface of the flints to be washed off by diluted muriatic acid.

"Make twelve more of broken or ground granite and twelve of broken or ground Portland stone."

In accordance with these instructions 38 bushels of Portland cement were procured; the gross weight being 4300 lbs. 11 oz., or 113·176 lbs. per bushel. When sifted through a sieve

of four hundred holes per square inch this was reduced to 4231 lbs. 4 oz., or 110·56 lbs. per bushel. About 36 lbs. were afterwards rubbed through the sieve; 34 lbs. would not pass, and there was a loss of 29 lbs. The sifted cement used in the following experiments, except when otherwise stated, weighed therefore 110·56 lbs. per "striked" bushel. A certain quantity of cement weighing 19·2 lbs. was sifted through a sieve of four hundred holes per square inch, 18 lbs. passing through and 1·2 lb. or one-sixteenth being left. Five moulds made of the sifted material neat were placed in water, and at the end of seven days broke at 959·4 lbs. = 427 lbs. per square inch. Five more moulds were made of the same cement unsifted, and under the same conditions broke at 842 lbs. = 375 lbs. per square inch. The gain by sifting was therefore about 14 per cent.

The following are the weights per bushel and per cubic foot of the materials used in the new series of experiments:—

Materials.	Weight of 1 Bushel.	Weight of 1 Cubic Foot.
	lbs.	lbs.
Portland cement	110·56	86·375
Sand and ballast	123·40	96·400
Portland stone	98·00	76·560
Broken granite	116·00	90·625
" pottery	113·00	88·280
" slag	107·00	83·594
" flints	126·00	98·440
" glass	120·00	93·750

Table 2, Series A, gives the strength of neat Portland cement used throughout these experiments at different periods from one day to twelve months; first, mixed by hand, and next, ground in a mortar-mill for thirty minutes. At the end of a month that which was ground in a mill had less than three-fourths the strength of that which was mixed by hand. The maximum strength of that mixed by hand seems to have been attained at five months, and that ground in a mortar-mill at one month, the greatest strength of the former being nearly double that of the latter. The strength of that which was mixed by hand was maintained, while that which was ground in a mortar-mill declined, from the maximum in each case to

the end of the experiments. This result was probably due partly to the process of crystallization, or setting, having been interrupted by the continued agitation, and partly to the destruction by attrition of the angular form of the particles.

Table 3, Series B, on the tensile strain required to separate bricks cemented together with Portland cement and lime mortars, would require to be greatly extended before any very trustworthy deductions could be made from them. The area from 36 inches to 40 inches is not large, and yet there are considerable mechanical difficulties in making this class of experiments with any machine which combines the necessary strength and delicacy. The pressed gault bricks show the lowest amount of adhesiveness ; partly because of their smooth surface, and partly because in making them some oily matter is used for lubricating the dies of the press through which they are passed before being burnt. In the case of the perforated gault bricks the cement-mortar seems to act as dowels, and the results are consequently high. The Suffolk and the Fareham red bricks, which each absorb about a pound of water per brick, adhere much better than the Staffordshire, which are not absorbent. This shows the importance of thoroughly soaking bricks which are to be put together with cement, as dry bricks deprive the cement-mortar of the moisture which is necessary for its setting.

Table 4, Series C, on the strength of Portland cement bricks tested by crushing, is, so far as it goes, instructive. As a rule, and as might be expected, the denser the brick, the greater its strength. When the cement is in proportion to the sand less than 1 to 2 or 1 to 3, those dried in air bear a greater pressure than those kept for twelve months in water. This would lead to the inference, that when the quantity of cement is small, bricks or blocks of concrete should be kept some time out of water, and be allowed to harden before being used.

Contrasting the strength of these concrete bricks with the different clay bricks as given in the first column of the Table 3, it will be seen that down to the proportion of 5 to 1 the former compare favourably. Thus, bricks made of neat cement bore a pressure equal to that of Staffordshire blue bricks or of best Fareham red bricks. Cement bricks made in proportions of from 2 to 1 of cement to 5 to 1 are equal to the picked clay bricks of the first six varieties in Table 3. It is further

evident that if these concrete bricks were more compressed their strength would be greatly increased. The compressed specimens in the Table were only from 3 to 9 per cent. denser than those not compressed. Further experiments on the relation of density to strength are most desirable.

The Tables referring to the D series show the strength of concrete blocks, or cubes, made with Portland cement mixed with various materials in different proportions and crushed after being kept a year, half of them in air and half in water. The general deductions from these Tables are, that the blocks made with the largest proportion of cement to ballast are the strongest—the strength being nearly in proportion to the quantity of cement; that it is desirable to spend no more time than is absolutely necessary to effect a thorough admixture of the cement with the sand and gravel ; and that the compressed blocks are apparently stronger than the uncompressed blocks in a larger proportion than their difference in density.

In this series Tables 4, 5, and 6 give the strength of 12-inch cubes of concrete made with ballast, Portland stone, broken granite, pottery, slag, flints, and glass, mixed with Portland cement in the proportions of 6 to 1, 8 to 1, and 10 to 1, and compressed. Half were kept in water for twelve months. Tables 7 to 12 give the strength of 6-inch cubes of concrete made of the same proportions and with the same materials, half of them compressed and half uncompressed. Some of these were kept in air and some in water for twelve months. Tables 13 to 18 exhibit the results of the six preceding Tables in another form.

The most prominent result of the D series of experiments is that concrete made of broken stone or broken pottery is much stronger than that made of gravel. This is no doubt due partly to the greater proportion of cement absorbed in the latter case in cementing the finer particles of sand, and partly to the want of angularity in the gravel. Compression and an increase in the proportion of cement alike increase strength. In making concrete bricks or blocks of moderate size compression might be applied with advantage; but with large masses of concrete it would be difficult to do so without running the risk of interrupting the process of crystallization or setting, which commences immediately on the application of moisture. The cost of labour

so applied would therefore be better employed in a larger admixture of cement. For the same reason that absorbent bricks should be thoroughly soaked with water before being used, the broken stones, bricks, or other materials used in making concrete should be saturated with water before the cement is applied.

Different illustrations of the Portland cement in the construction of sewers for the Main Drainage of London, and of the Albert or Southern Embankment of the river Thames, are shown in Plate 15.[1] It will be observed that in some cases it has only been used as a foundation, or as a backing for brickwork; while in other instances sewers, 4 feet 6 inches high by 3 feet wide, of concrete, have been lined with brickwork $4\frac{1}{2}$ inches thick (Fig. 7). Again, some sewers have been formed entirely of concrete, in the proportion of 1 of cement to 6 of sand (Figs. 8, 9, and 10). There have been constructed in the metropolis, south of the Thames, 5440 lineal feet of concrete sewers, lined with $4\frac{1}{2}$-inch brickwork, and 6800 lineal feet (about $1\frac{1}{4}$ mile) of sewers entirely of concrete. The details of these will be found in Table 5 in the Appendix. The cost of this concrete is less than half that of brickwork, but if rendered inside with cement it is about the same as if lined with half brick—perhaps the cheapest form of sewer combining strength with soundness. Sewers and culverts of almost any size might be made on this principle. Sewers of concrete not rendered inside, though somewhat cheaper, have one practical disadvantage in busy thoroughfares, inasmuch as they require a longer length of centering, on account of the slow setting of the concrete, and it is therefore necessary that about double the length of trench should be open at one time. Fig. 8 shows the invert-mould for forming the lower half of concrete sewers. Iron ribs are set up 12 feet apart, and narrow laggings are inserted between them. The concrete is put in and rammed behind the latter. The centre is planed smooth, and if the internal face is not to be rendered the centre is greased to prevent the concrete adhering. Where the arch is not to be ren-

[1] In the Appendix, page 146, will be found "Extracts from the Specifications for Sewers made of Portland Cement Concrete and Concrete lined with Brickwork."

dered, fine concrete, composed of sand instead of gravel, is put next to the centre. The cost of the concrete sewer, 4 feet by 2 feet 8 inches (Fig. 9), was 10*s.* per lineal foot, exclusive of excavation. Under the same contract a brick sewer, of the same size, 9 inches thick (Fig. 6), cost 16*s.* 6*d.* per lineal foot. The concrete sewer, 7 feet 1 inch in diameter (Fig. 10), cost per lineal foot, irrespective of earthwork, 16*s.*; but inclusive of earthwork, side entrances, junctions, &c., it was about 23*s.* per lineal foot. This sewer was in some respects exceptional, inasmuch as it consisted of little more than an arch over a previously existing invert; the lower half was, however, rendered with cement and sand, in equal proportions, 1 inch thick. Everything being taken into consideration, the most economical combination is 4½ inches of brickwork in cement and the rest in concrete. Another sewer, 9 feet 6 inches by 9 feet 6 inches, to be constructed of concrete with a lining of 4½-inch brickwork in cement, is shown in Fig. 11.

In the construction of the Albert, or Southern Embankment of the river Thames (Fig. 12), it was originally intended to form the wall of brickwork, with a granite facing; but after about a fourth part of the work had been executed, 14,335 cubic yards of Portland cement concrete, made in the proportion of 6 to 1, at 11*s.* per cubic yard, were substituted for an equal quantity of brickwork at 30*s.* per cubic yard. In the No. 3 contract of the Victoria Embankment about 15,000 cubic yards of Portland cement concrete were used instead of brickwork. The Chelsea Embankment Wall, soon to be commenced, will be formed of about 25,000 cubic yards of cement concrete, faced with about 5000 cubic yards of granite (Fig. 13).

From the experience already gained in the use of Portland cement concrete, there would seem to be hardly any limit to the purposes to which it may be applied. It is gradually being brought into use in the construction of dwelling-houses in different parts of the country, and there is no doubt it will be still more extensively employed in the construction of docks, piers, breakwaters, and other massive engineering works. Mr. Joseph Mitchell, M. Inst. C.E., has tried Portland cement concrete, made of broken granite and cement, and laid on about 6 inches thick, at Inverness, Edinburgh, and in London, as a

substitute for ordinary metalling for the surfaces of the streets of towns.

Many experiments have been made in the manufacture of bricks of different proportions of Portland cement and sand. As these can be made equal, if not superior, both in strength and appearance, to most kinds of clay bricks, it is difficult to understand why they are not manufactured as a substitute for clay bricks in localities where the latter are dear. Probably, however, it is only a question of time. Where concrete can be used in a mass it is cheaper than when used in the form of blocks, and still cheaper than in the form of bricks. Each of these modes has its advantages, according to the nature of the work.

In France it has been long used in the form of "Bétons Aggloméres." In 1867 a number of arches were formed with it by M. Coignet, under the steps leading from Westminster Bridge to the Albert Embankment, and also about 40 feet of sewer, 4 feet by 2 feet by 8 inches, in the Camberwell Road. Similar arches and sewers were constructed of Portland cement concrete, and the general result was that the Portland cement concrete was both stronger and cheaper than the béton.

In the construction of a sewer at Dulwich, where a cement weighing 118 lbs. per bushel was used, considerable quantities of milky-looking fluid exuded from the joints for a few weeks after the work was completed. This was probably the result of an excessive proportion of chalk having been used in the manufacture of the cement. With the view of ascertaining whether or not the cement deteriorated with age, the tests shown in Table 6 were made first with neat cement, then with cement and sand in equal proportions. It was satisfactorily ascertained that in both cases the cement continued to harden during the three months over which the experiments extended. The neat cement at seven days bore a tensile strain of 805·2 lbs., and gradually increased in strength to 1239 lbs. at three months. The mortar composed of cement and sand in equal proportions, stood a strain of 275·8 lbs. at the end of a week, and 538·6 lbs. at three months. The strength of the latter mixture increased from 34 per cent. of the neat to 43·4 per cent.; and had the experiments been extended over a year

or more, analogy would lead to the conclusion that this proportion would have continued to increase.

Table 7 gives the strength of 589,217 bushels of Portland cement used during the last five years on various works south of the Thames. The cement has borne an average tensile strain at the end of a week of 806·63 lbs., equal to 358·5 lbs. per square inch; being an improvement on that reported five years ago of 200 lbs. on the breaking area of 2¼ square inches, or 89 lbs. per square inch. It is satisfactory to know that the quality has not only been maintained, but has continued to improve. The strength at the end of thirty days of 37,200 bushels of the same cement, as ascertained by eleven hundred and eighty tests, averaged 1024 lbs., equal to 455 lbs. per square inch, showing an average of 234 lbs., or 30 per cent. over the cement tested at seven days, which broke at 790 lbs. Wherever the nature of the work will admit of it, tests at the end of a month will be found more satisfactory than if made earlier, as heavy cements, though the strongest eventually, are the slowest to set.

The standard originally specified, 400 lbs., on 2¼ square inches, was soon afterwards raised to 500 lbs., or 222 lbs. per square inch. This has since been increased to 350 lbs. per square inch, or 787 lbs. on the breaking area at seven days (Table 8). A standard of 450 lbs. per square inch at thirty days would be about an equivalent practical test to specify. For the purpose of comparison the same sectional area at the breaking point (2·25 inches) has been retained, though various experiments, already described, have been made as to different forms.

Further experience has confirmed the earlier conclusions, that the strength of Portland cement increases with its specific gravity, its more perfect pulverization, and its thorough admixture with the minimum quantity of water in forming mortar. It has also shown that to effect perfect cohesion, it is of the utmost importance that the bricks to be cemented together should be thoroughly saturated with water. Dry bricks absorb moisture from the cement and destroy it.

Heavy cement, weighing 123 lbs. a bushel, like that referred to in Table XVIII., takes about two years to attain to its maximum strength used neat: the admixture of sand not only

reduces its strength, but prolongs the period during which its strength increases—in other words, by the admixture of sand or gravel, cement-mortar or concrete sets less rapidly than neat cement.

Roman cement, though from its quick-setting property very valuable for many purposes, deteriorates by exposure to the air before use, and is about double the cost of Portland cement if measured by strength.

APPENDIX.

TABLE XVIII., in Appendix to Paper 1865–6, extended to Seven Years.[1]

Results of Experiments with Portland Cement, weighing 123 lbs. to the Imperial Bushel, mixed neat, and with an equal proportion of clean Thames Sand, showing the Breaking Weight on a Sectional Area of 2·25 Square Inches. The original Form of Mould is shown in Plate 2, vol. xxv., and in Table I., No. 1, of the Appendix to the present Paper.

These form parts of a Series intended to extend over Ten Years. The whole of the Specimens were kept in Water from the Time of their being made till the time of Testing.

AGE.	Neat Cement.	1 of Cement to 1 of Sand.
	Average Breaking Test of 10 Experiments.	Average Breaking Test of 10 Experiments.
	lbs.	lbs.
7 Days	817·1	353·2
1 Month	935·8	452·5
3 Months	1055·9	547·5
6 ditto	1176·6	640·3
9 ditto	1219·5	692·4
12 ditto	1229·7	716·6
2 Years	1324·9	790·3
3 ditto	1314·4	784·7
4 ditto	**1312·6**	**818·1**
5 ditto	**1306·0**	**821·0**
6 ditto	**1308·0**	**819·5**
7 ditto	**1327·3**	**863·6**

TABLE XXIV., in Appendix to Paper 1865–6, extended to Seven Years.

Results of Experiments with Roman Cement, weighing 80 lbs. to the Imperial Bushel. Manufactured by Messrs. COLES, SHADBOLT, and Co. Sectional Area, 2·25 Square Inches. Original Mould.

TIME KEPT IMMERSED IN WATER.	Neat Cement.		
	Minimum Breaking Test.	Maximum Breaking Test.	Average Breaking Test.
	lbs.	lbs.	lbs.
7 Days	180	213	201·83
14 ditto	130	215	168·00
21 ditto	200	253	221·14
1 Month	173	283	243·33
3 Months	238	400	329·60
6 ditto	252	408	376·80
9 ditto	78	306	167·80
12 ditto	137	428	323·80
2 Years	**377**	**472**	**438·00**
3 ditto	**425**	**462**	**450·80**
4 ditto	**454**	**574**	**512·60**
5 ditto	**442**	**494**	**466·90**
6 ditto	**447**	**487**	**466·60**
7 ditto	**488**	**620**	**553·20**

[1] In Tables XVIII. and XXIV., the darker type refers to the later experiments.

TABLE XXV., in Appendix to Paper 1865–6, extended to Seven Years.[1]

Results of Experiments with Roman Cement. Manufactured by Messrs. J. B. WHITE and BROTHERS. Sectional Area, 2·25 Square Inches. Original Mould.

TIME KEPT IMMERSED IN WATER.	Neat Cement.		
	Minimum Breaking Test.	Maximum Breaking Test.	Average Breaking Test.
	lbs.	lbs.	lbs.
7 Days	170	240	202·0
14 ditto	160	190	173·0
21 ditto	170	205	186·5
1 Month	246	291	260·3
3 Months	307	344	322·5
6 ditto	442	502	472·7
9 ditto	313	520	471·1
12 ditto	596	680	643·1
2 Years	**577**	**610**	**546·3**
3 ditto	**522**	**647**	**603·8**
4 ditto	**600**	**658**	**632·2**
5 ditto	**582**	**662**	**627·4**
6 ditto	**603**	**711**	**666·4**
7 ditto	**646**	**780**	**708·7**

TABLE XXIX., in Appendix to Paper 1865–6, extended to Seven Years.

Results of Experiments with Medina Cement. Manufactured by Messrs. FRANCIS BROTHERS, 1864. Sectional Area, 2·25 Square Inches. Original Mould.

TIME KEPT IMMERSED IN WATER.	Neat Cement.		
	Minimum Breaking Test.	Maximum Breaking Test.	Average Breaking Test.
	lbs.	lbs.	lbs.
7 Days	83	100	92·1
ditto (2nd series)	195	235	211·0
14 Days	238	335	303·4
21 ditto	274	332	298·0
1 Month	210	346	306·0
3 Months	420	468	448·8
6 ditto	376	438	412·4
9 ditto	438	507	457·2
12 ditto	456	527	476·9
2 Years	235	328	276·0
3 ditto	**200**	**342**	**275·5**
4 ditto	**236**	**430**	**287·8**
5 ditto	**245**	**395**	**307·0**
6 ditto	**309**	**475**	**365·0**
7 ditto	**335**	**440**	**377·5**

[1] In Tables XXV. and XXIX. the darker type refers to the later experiments.

TABLE 1.

Results of Experiments on different Forms of Moulds. Weight of Portland Cement used, 114 lbs. per Bushel. October and November, 1866.

No.	Form.	Dimensions at Breaking Point.	At 7 Days. Breaking Weight.	At 7 Days. Breaking Weight per Square Inch.	At 7 Days. Average per Square Inch.	At 30 Days. Breaking Weight.	At 30 Days. Breaking Weight per Square Inch.	At 30 Days. Average per Square Inch.
1		" " 1½ × 1½	778·1	345·8	..	1010·7	449·2	
2		ditto	1034·7	459·9	..	1151·6	511·8	
3		ditto	1064·3	473·0	..	1145·4	509·0	
4		ditto	918·9	408·4	..	969·0	430·66	
5		ditto	924·0	410·6	..	967·0	429·8	422
6		ditto	860·0	382·2	..	912·1	405·4	
7		" " 2 × 2	1199·2	300·0		1354·7	338·7	
8		ditto	1172·6	293·0	297	1315·1	328·8	337
9		ditto	1190·5	297·6		1371·2	342·8	
10		ditto	1286·3	321·6	..	1460·3	365·0	

TABLE 2. SERIES A.

Experiments on Cement mixed by Hand and in a Mortar-Mill. The Form of Mould is shown in Table 1, No. 2. Sectional Area, 2·25 Square Inches. 1868. Average of Ten Experiments in each case.

Cement, 110·56 lbs. to the Bushel. Mixed by hand.		Cement, 110·56 lbs. to the Bushel. Ground in a Mortar-Mill for 30 Minutes.	
1 Day ..	362·1	1 Day ..	341·1
2 Days ..	509·8	2 Days ..	388·1
3 " ..	698·3	3 " ..	478·3
4 " ..	765·0	4 " ..	512·6
5 " ..	794·4	5 " ..	563·7
6 " ..	829·8	6 " ..	604·1
7 " ..	897·5	7 " ..	613·2
1 Month	1096·3	1 Month	755·8
2 Months	1215·0	2 Months	557·7
3 " ..	1220·0	3 " ..	611·6
4 " ..	1422·9	4 " ..	521·9
5 " ..	1435·6	5 " ..	504·8
6 " ..	1424·9	6 " ..	538·2
7 " ..	1357·8	7 " ..	451·4
8 " ..	1360·1	8 " ..	637·8
9 " ..	1372·4	9 " ..	496·6—3 moulds broke.
10 " ..	1381·1	10 " ..	Nil—all moulds broke.
11 " ..	1387·1	11 " ..	256·4—2 moulds broke.
12 " ..	1396·5	12 " ..	443·2

TABLE 3. SERIES B. SUMMARY OF TESTS.[1]

TENSILE Strain required to separate Bricks cemented together in Blocks

DESCRIPTION OF BRICK.	Average Strength by Compression per Brick in Tons.	Dimensions in Inches.					
		Length.	Breadth.	Thickness.	Area.		Cubical Contents.
					Bed.	Edge.	
		ins.	ins.	ins.	ins.	ins.	ins.
Gault clay, pressed	40·04	8·75	4·125	2·75	36·09	24·06	99·25
Gault clay, wire cut	32·70	9·00	4·125	2·75	37·125	24·75	102·09
Gault clay, perforated	46·40	9·00	4·375	2·625	39·375	24·625	103·48
Suffolk	34·94	9·00	4·5	2·625	40·5	23·625	106·312
Stock	38·74	9·00	4·125	2·625	37·125	23·125	97·45
Fareham red	90·40	8·75	4·125	2·625	36·01	22·97	94·74
Staffordshire blue (pressed, with frog)	111·04	8·75	4·125	2·75	36·09	24·06	99·25
Staffordshire blue (rough, without frog)	117·92	8·75	4·125	2·75	36·09	24·06	99·25

[1] The details of this Series may be consulted at the Institution.

TABLE 3. SERIES B. SUMMARY OF TESTS.

of 4 with Portland Cement and Lime Mortars, at end of 12 Months.

Weight. in lbs.		Tensile Strain in lbs.									Set in Air or Water.
		Portland Cement and Sand.						Lime and Sand.			
Dry.	Wet.	Neat.	1 to 1.	2 to 1.	3 to 1.	4 to 1.	5 to 1.	1 to 2 Blue Lias.	1 to 2 Dorking.	1 to 2 Chalk.	
·13	6·47	1631·4	1576·4	871·	988·2	735·2	Broke in drilling	1448·0	1520·5	638·7	Air.
		1673·4	1642·	1708·	1264·	750·3		..	..	..	Water.
5·86	6·85	2440·	1558·3	Not set.	1037·	791·	772·	Not set.	Not set.	679·4	Air.
		1679·	1408·3	Not set.	Not set.	Not set.	Not set.	..	..	..	Water.
4·95	5·76	3898·8	2982·	2231·6	1663·2	1088·6	812·6	1763·0	1349·3	547·0	Air.
		3011·	2721·	1834·4	1561·4	933·2	641·	..	..	..	Water.
6·18	7·14	3275·2	2346·	2247·	2030·6	1930·6	1337·	2372·0	1788·2	428·6	Air.
		3231·	2484·	2238·	1934·4	1869·	1154·2	..	..	..	Water.
5·	5·57	2816·8	2264·	1571·8	1516·2	825·8	792·6	1210·6	1479·3	423·8	Air.
		3445·	2455·	2009·	1580·8	1259·6	845·6	..	..	..	Water.
6·55	7·52	4538·	2990·	2064·	1499·	1236·	1040·	1919·0	1743·0	449·0	Air.
		4449·	2237·	1917·	1128·	1145·	653·	..	..	..	Water.
7·82	7·90	2563·4	2008·	1844·	1535·	1183·	752·	1102·7	1330·6	Not set.	Air.
		2749·	1329·	1304·	1053·	1016·	718·	..	..	..	Water.
7·75	7·81	1744·4	1701·6	1746·	1299·6	988·	Not set.	1269·6	1030·8	Not set.	Air.
		1451·	1048·2	1186·	1090·	843·	Not set.	..	..	..	Water.

TABLE 4. SERIES C. SUMMARY OF TESTS. PORTLAND CEMENT Bricks (9 × 4½ × 3)

	Cement.				Sand.				Water.	
	Compressed.		Not Compressed.		Compressed.		Not Compressed.		Compressed.	
	Measure.	Weight.	Measure.	Weight.	Measure.	Weight.	Measure.	Weight.	Measure.	Weight.
Neat	4·64	8·03	..	..	Nil.	Nil.	Nil.	Nil.	1·375	1·65
,,	,,	,,	..	..	,,	,,	,,	,,	,,	,,
,,	..	..	4·34	7·50	,,	,,	,,	,,	..	..
,,	..	..	,,	,,	,,	,,	,,	,,	..	..
1 to 1	2·39	4·13	..	..	2·38	4·60	..	..	·875	1·05
,,	,,	,,	..	..	,,	,,	..	..	,,	,,
,,	..	..	2·42	4·19	..	..	2·31	4·45	..	..
,,	..	..	,,	,,	..	..	,,	,,	..	..
2 to 1	1·63	2·82	..	..	2·83	5·46	..	..	·75	·90
,,	,,	,,	..	..	,,	,,	..	..	,,	,,
,,	..	..	1·45	2·51	..	..	2·91	5·62	..	..
,,	..	..	,,	,,	..	..	,,	,,	..	..
3 to 1	1·14	1·97	..	..	3·43	6·62	..	..	·625	·75
,,	,,	,,	..	..	,,	,,	..	..	,,	,,
,,	..	..	1·06	1·83	..	..	3·19	6·14	..	..
,,	..	..	,,	,,	..	..	,,	,,	..	..
4 to 1	·88	1·53	..	..	3·55	6·85	..	..	·50	·60
,,	,,	,,	..	..	,,	,,	..	..	,,	,,
,,	..	..	·82	1·42	..	..	3·29	6·36	..	..
,,	..	..	,,	,,	..	..	,,	,,	..	..
5 to 1	·72	1·25	..	..	3·64	7·02	..	..	·50	·60
,,	,,	,,	..	..	,,	,,	..	..	,,	,,
,,	..	..	·68	1·18	..	..	3·43	6·62	..	..
,,	..	..	,,	,,	..	..	,,	,,	..	..
6 to 1	·60	1·04	..	..	3·64	7·03	..	..	·375	·45
,,	,,	,,	..	..	,,	,,	..	..	,,	,,
,,	..	..	·58	1·00	..	..	3·48	6·71	..	..
,,	..	..	,,	,,	..	..	,,	,,	..	..
7 to 1	·52	·90	..	..	3·71	7·15	..	..	·375	·45
,,	,,	,,	..	..	,,	,,	..	..	,,	,,
,,	..	..	·48	·84	..	..	3·44	6·64	..	..
,,	..	..	,,	,,	..	..	,,	,,	..	..
8 to 1	·46	·80	..	..	3·75	7·24	..	..	·375	·45
,,	,,	,,	..	..	,,	,,	..	..	,,	,,
,,	..	..	·43	·74	..	..	3·44	6·63	..	..
,,	..	..	,,	,,	..	..	,,	,,	..	..
9 to 1	·42	·73	..	..	3·82	7·36	..	..	·375	·45
,,	,,	,,	..	..	,,	,,	..	..	,,	,,
,,	..	..	·39	·66	..	..	3·48	6·72	..	..
,,	..	..	,,	,,	..	..	,,	,,	..	..
10 to 1	·39	·66	..	..	3·84	7·41	..	..	·375	·45
,,	,,	,,	..	..	,,	,,	..	..	,,	,,
,,	..	..	·36	·60	..	..	3·52	6·79	..	..
,,	..	..	,,	,,	..	..	,,	,,	..	..

Neat, and with different proportions of Sand, tested by Crushing in a Hydraulic Press.

Water.		Average Weight of Five Moulds, One Year Old.				Broke at Tons.				—
Not Compressed.		Compressed.		Not Compressed.		Compressed.		Not Compressed.		
Measure.	Weight.	Air.	Water.	Air.	Water.	Air.	Water.	Air.	Water.	
..	..	9·51	..	..	..	96·60	..	..	..	Neat.
..	..	..	9·76	..	..	..	132·62	..	..	,,
1·625	1·75	..	..	9·24	..	..	..	112·46	..	,,
,,	,,	..	..	..	9·47	..	..	..	113·86	,,
..	..	9·65	..	..	..	82·80	..	..	..	1 to 1
..	..	..	9·93	..	..	..	83·32	..	..	,,
1·1225	1·35	..	..	9·28	..	..	..	63·26	..	,,
,,	,,	..	..	..	9·67	..	..	..	62·74	,,
..	..	9·14	..	..	..	70·00	..	..	..	2 to 1
..	..	..	9·59	..	..	..	57·14	..	..	,,
1·00	1·20	..	..	8·85	..	..	..	41·48	..	,,
,,	,,	..	..	..	9·25	..	..	..	39·40	,,
..	..	9·13	..	..	..	53·80	..	..	..	3 to 1
..	..	..	9·56	..	..	..	26·60	..	..	,,
·9375	1·12	..	..	8·50	..	..	..	26·50	..	,,
,,	,,	..	..	..	6·30	..	..	..	21·70	,,
..	..	8·79	..	..	..	43·60	..	..	..	4 to 1
..	..	..	9·51	..	..	..	29·92	..	..	,,
·9375	1·12	..	..	8·24	..	..	..	19·82	..	,,
,,	,,	..	..	..	9·08	..	..	..	13·72	,,
..	..	8·64	..	..	..	37·40	..	..	..	5 to 1
..	..	..	9·48	..	..	..	15·10	..	..	,,
·875	1·05	..	..	8·15	..	..	..	15·28	..	,,
,,	,,	..	..	..	8·86	..	..	..	8·60	,,
..	..	8·43	..	..	..	30·28	..	..	..	6 to 1
..	..	..	9·38	..	..	..	11·24	..	..	,,
·875	1·05	..	..	7·94	..	..	..	11·00	..	,,
,,	,,	..	..	..	8·73	..	..	..	5·78	,,
..	..	8·40	..	..	..	28·88	..	..	..	7 to 1
..	..	..	9·37	..	..	..	10·54	..	..	,,
·875	1·05	..	..	7·84	..	..	..	9·05	..	,,
..	,,	..	..	..	8·70	..	..	..	4·26	,,
..	..	8·33	..	..	..	19·24	..	..	..	8 to 1
..	..	..	9·43	..	..	..	8·18	..	..	,,
·875	1·05	..	..	7·69	..	..	..	7·06	..	,,
,,	,,	..	..	..	8·56	..	..	..	2·32	,,
..	..	8·36	..	..	..	17·52	..	..	..	9 to 1
..	..	..	9·25	..	..	..	7·42	..	..	,,
·875	1·05	..	..	7·68	..	..	..	5·32	..	,,
,,	,,	..	..	..	8·54	..	..	..	2·32	,,
..	..	8·27	..	..	..	15·44	..	..	..	10 to 1
..	..	..	9·30	..	..	..	5·62	..	..	,,
·875	1·05	..	..	7·61	..	..	..	4·80	..	,,
,,	,,	..	..	..	8·75	..	..	..	2·28	,,

C Series.—CEMENT BRICKS.

Portland Cement Bricks (9″ × 4½″ × 3″)—Neat, and with different Proportions of Sand, tested by Crushing in Hydraulic Press.

Weight of one Bushel of Cement, 110·56 lbs.

Cement, Neat.

—		Weight of Five Moulds after being kept One Year.		Broke at Tons.		Number of Test.	Remarks.
		In Air.	In Water.	In Air.	In Water.		
		lbs.	lbs.				
Cement	Measure 4·34 pints.	9·25	..	120·0	..	101	Not Compressed.
	Weight 7·50 lbs.	9·20	..	110·1	..	102	
Sand	Measure Nil. ..	9·25	..	114·6	..	103	
	Weight Nil. ..	9·25	..	107·0	..	104	
Water	Measure 1·625 pint.	9·26	..	110·6	..	105	
	Weight 1·75 lb.	..	9·46	..	111·4	106	
When Moulded	Oct. 1, 1867.	..	9·46	..	115·4	107	
		..	9·46	..	112·9	108	
When Tested	Oct. 1, 1868.	..	9·47	..	116·2	109	
		..	9·50	..	113·4	110	
		9·24	9·47	112·46	113·86	Average.	
Cement	Measure 4·64 pints.	9·51	..	90·0	..	101	Compressed.
	Weight 8·03 lbs.	9·50	..	96·5	..	102	
Sand	Measure Nil. ..	9·52	..	100·0	..	103	
	Weight Nil. ..	9·54	..	97·3	..	104	
Water	Measure 1·375 pint.	9·50	..	99·2	..	105	
	Weight 1·65 lb.	..	9·80	..	118·0	106	
When Moulded	Oct. 7, 1867.	..	9·75	..	143·8	107	
		..	9·73	..	128·1	108	
When Tested	Oct. 7, 1868.	..	9·78	..	146·2	109	
		..	9·75	..	127·0	110	
		9·51	9·76	96·60	132·62	Average.	

Proportion of Sand, 1 to 1.

Cement	Measure 2·42 pints.	9·27	..	65·0	..	91	Not Compressed.
	Weight 4·19 lbs.	9·28	..	64·6	..	92	
Sand	Measure 2·31 pints.	9·30	..	64·5	..	93	
	Weight 4·45 lbs.	9·32	..	62·2	..	94	
Water	Measure 1·2225 pint.	9·25	..	60·0	..	95	
	Weight 1·35 lb.	..	9·66	..	57·6	96	
When Moulded	Sept. 30, 1867.	..	9·64	..	74·0	97	
		..	9·64	..	56·8	98	
When Tested	Sept. 30, 1868.	..	9·70	..	56·9	99	
		..	9·70	..	68·4	100	
		9·28	9·67	63·26	62·74	Average.	

C Series.—CEMENT BRICKS—*continued.*

Portland Cement Bricks (9″ × 4½″ × 3″)—Neat, and with different Proportions of Sand, tested by Crushing in Hydraulic Press.

Weight of one Bushel of Cement, 110·56 lbs.

Proportion of Sand, 1 to 1—*continued.*

——			Weight of Five Moulds after being kept One Year. In Air.	Weight of Five Moulds after being kept One Year. In Water.	Broke at Tons. In Air.	Broke at Tons. In Water.	Number of Test.	Remarks.
			lbs.	lbs.				
Cement	Measure	2·39 pints.	9·65	..	85·0	..	91	Compressed.
	Weight	4·13 lbs.	9·67	..	84·0	..	92	
Sand	Measure	2·38 pints.	9·67	..	78·2	..	93	
	Weight	4·60 lbs.	9·65	..	85·6	..	94	
Water	Measure	0·875 pint.	9·63	..	81·2	..	95	
	Weight	1·05 lb.	..	9·91	..	88·2	96	
When Moulded	Oct. 7, 1867.		..	9·95	..	84·0	97	
			..	9·92	..	83·5	98	
When Tested	Oct. 7, 1868.		..	9·93	..	79·3	99	
			..	9·93	..	81·6	100	
			9·65	9·93	82·8	83·32	Average.	

Proportion of Sand, 2 to 1.

Cement	Measure	1·45 pint.	8·90	..	39·6	..	81	Not Compressed.
	Weight	2·51 lbs.	8·85	..	39·6	..	82	
Sand	Measure	2·91 pints.	8·85	..	42·4	..	83	
	Weight	5·62 lbs.	8·83	..	43·0	..	84	
Water	Measure	1·00 pint.	8·83	..	42·8	..	85	
	Weight	1·20 lb.	..	9·20	..	39·4	86	
When Moulded	Sept. 30, 1867.		..	9·26	..	39·4	87	
			..	9·30	..	39·8	88	
When Tested	Sept. 30, 1868.		..	9·28	..	39·2	89	
			..	9·20	..	39·2	90	
			8·85	9·25	41·48	39·40	Average.	
Cement	Measure	1·63 pint.	9·15	..	71·0	..	81	Compressed.
	Weight	2·82 lbs.	9·15	..	69·0	..	82	
Sand	Measure	2·83 pints.	9·13	..	68·2	..	83	
	Weight	5·46 lbs.	9·14	..	70·8	..	84	
Water	Measure	0·75 pint.	9·13	..	71·0	..	85	
	Weight	0·90 lb.	..	9·60	..	59·5	86	
When Moulded	Oct. 5, 1867.		..	9·61	..	56·0	87	
			..	9·57	..	55·0	88	
When Tested	Oct. 5, 1868.		..	9·58	..	60·0	89	
			..	9·58	..	55·2	90	
			9·14	9·59	70·0	57·14	Average.	

C Series.—CEMENT BRICKS—*continued.*

Portland Cement Bricks ($9'' \times 4\frac{1}{2}'' \times 3''$)—Neat, and with different Proportions of Sand, tested by Crushing in Hydraulic Press.

Weight of one Bushel of Cement, 110·56 lbs.

Proportion of Sand, 3 to 1.

—		Weight of Five Moulds after being kept One Year.		Broke at Tons.		Number of Test.	Remarks.
		In Air.	In Water.	In Air.	In Water.		
		lbs.	lbs.				
Cement	Measure 1·06 pint.	8·50	..	27·0	..	71	Not Compressed.
	Weight 1·83 lb.	8·47	..	26·0	..	72	
Sand	Measure 3·19 pints.	8·45	..	26·0	..	73	
	Weight 6·14 lbs.	8·55	..	27·0	..	74	
Water	Measure 0·9375 pint.	8·53	..	26·5	..	75	
	Weight 1·12 lb.	..	9·34	..	22·6	76	
When Moulded	Sept. 28, 1867.	..	9·31	..	18·4	77	
		..	9·30	..	22·5	78	
When Tested	Sept. 28, 1868.	..	9·36	..	22·8	79	
		..	9·32	..	22·2	80	
		8·50	9·32	26·50	21·70	Average.	
Cement	Measure 1·14 pint.	9·15	..	52·2	..	71	Compressed.
	Weight 1·97 lb.	9·13	..	54·8	..	72	
Sand	Measure 3·43 pints.	9·15	..	55·0	..	73	
	Weight 6·62 lbs.	9·12	..	53·0	..	74	
Water	Measure 0·625 pint.	9·12	..	54·0	..	75	
	Weight 0·75 lb.	..	9·58	..	28·4	76	
When Moulded	Oct. 5, 1867.	..	9·54	..	26·0	77	
		..	9·55	..	26·0	78	
When Tested	Oct. 5, 1868.	..	9·60	..	26·4	79	
		..	9·52	..	26·2	80	
		9·13	9·56	53·80	26·60	Average.	

Proportion of Sand, 4 to 1.

Cement	Measure 0·82 pint.	8·28	..	20·0	..	61	Not Compressed.
	Weight 1·42 lb.	8·20	..	19·2	..	62	
Sand	Measure 3·29 pints.	8·24	..	20·4	..	63	
	Weight 6·36 lbs.	8·20	..	20·0	..	64	
Water	Measure 0·9375 pint.	8·28	..	19·5	..	65	
	Weight 1·12 lb.	..	9·05	..	14·0	66	
When Moulded	Sept. 27, 1867.	..	9·07	..	14·2	67	
		..	9·10	..	13·5	68	
When Tested	Sept. 27, 1868.	..	9·10	..	13·5	69	
		..	9·09	..	13·4	70	
		8·24	9·08	19·82	13·72	Average.	

C Series.—CEMENT BRICKS—*continued.*

Portland Cement Bricks (9″ × 4½″ × 3″)—Neat, and with different Proportions of Sand, tested by Crushing in Hydraulic Press.

Weight of one Bushel of Cement, 110·56 lbs.

Proportion of Sand, 4 to 1—*continued.*

—	Weight of Five Moulds after being kept One Year.		Broke at Tons.		Number of Test.	Remarks.
	In Air.	In Water.	In Air.	In Water.		
	lbs.	lbs.				
Cement — Measure 0·88 pint.	8·80	..	45·0	..	61	Compressed.
Cement — Weight 1·53 lb.	8·81	..	44·0	..	62	
Sand — Measure 3·55 pints.	8·80	..	43·0	..	63	
Sand — Weight 6·85 lbs.	8·76	..	43·0	..	64	
Water — Measure 0·50 pint.	8·79	..	43·0	..	65	
Water — Weight 0·60 lb.	..	9·50	..	23·2	66	
When Moulded — Oct. 4, 1867.	..	9·56	..	20·0	67	
	..	9·50	..	21·4	68	
When Tested — Oct. 5, 1868.	..	9·50	..	20·0	69	
	..	9·50	..	20·0	70	
	8·79	9·51	43·60	20·92	Average.	

Proportion of Sand, 5 to 1.

—	Weight of each Brick, being the average of Five after being kept One Year.		Broke at Tons.		Number of Tests.	Remarks.
	In Air.	In Water.	In Air.	In Water.		
	lbs.	lbs.				
Cement — Measure 0·68 pint.	8·12	..	15·8	..	51	Not Compressed.
Cement — Weight 1·18 lb.	8·17	..	14·6	..	52	
Sand — Measure 3·43 pints.	8·19	..	15·8	..	53	
Sand — Weight 6·62 lbs.	8·15	..	15·2	..	54	
Water — Measure 0·875 pint.	8·15	..	15·0	..	55	
Water — Weight 1·05 lb.	..	8·86	..	8·7	56	
When Moulded — Sept. 26, 1867.	..	8·92	..	8·5	57	
	..	8·84	..	9·0	58	
When Tested — Sept. 26, 1868.	..	8·86	..	8·5	59	
	..	8·83	..	8·3	60	
	8·15	8·86	15·28	8·60	Average.	

C Series.—CEMENT BRICKS—*continued.*

Portland Cement Bricks ($9'' \times 4\frac{1}{2}'' \times 3''$)—Neat, and with different Proportions of Sand, tested by Crushing in Hydraulic Press.

Weight of one Bushel of Cement, 110·50 lbs.

Proportion of Sand, 5 to 1—*continued.*

—		Weight of each Brick, being the average of Five after being kept One Year. In Air.	Weight of each Brick, being the average of Five after being kept One Year. In Water.	Broke at Tons. In Air.	Broke at Tons. In Water.	Number of Test.	Remarks.
		lbs.	lbs.				
Cement	Measure 0·72 pint.	8·64	..	37·0	..	51	
	Weight 1·25 lb.	8·64	..	37·0	..	52	Compressed.
Sand	Measure 3·64 pints.	8·65	..	37·5	..	53	
	Weight 7·02 lbs.	8·63	..	38·5	..	54	
Water	Measure 0·50 pint.	8·63	..	37·0	..	55	
	Weight 0·60 lb.	..	9·50	..	15·0	56	
When Moulded	Oct. 4, 1867.	..	9·50	..	15·8	57	
		..	9·54	..	15·2	58	
When Tested	Oct. 5, 1868.	..	9·47	..	15·0	59	
		..	9·40	..	14·5	60	
		8·64	9·48	37·40	15·10	Average.	

Proportion of Sand, 6 to 1.

—		In Air.	In Water.	In Air.	In Water.	Number of Test.	Remarks.
Cement	Measure 0·58 pint.	7·98	..	10·5	..	41	
	Weight 1 00 lb.	7·95	..	11·0	..	42	Not Compressed.
Sand	Measure 3·48 pints.	7·90	..	11·0	..	43	
	Weight 6·71 lbs.	7·98	..	11·0	..	44	
Water	Measure 0·875 pint.	7·90	..	11·5	..	45	
	Weight 1·05 lb.	..	8·80	..	6·4	46	
When Moulded	Sept. 26, 1867.	..	8·85	..	5·9	47	
		..	8·67	..	5·9	48	
When Tested	Sept. 26, 1868.	..	8·65	..	5·5	49	
		..	8·68	..	5·2	50	
		7·94	8·73	11·00	5·78	Average.	
Cement	Measure 0·60 pint.	8·40	..	30·6	..	41	
	Weight 1·04 lb.	8·41	..	30·4	..	42	Compressed.
Sand	Measure 3·64 pints.	8·44	..	30·4	..	43	
	Weight 7·03 lbs.	8·44	..	30·0	..	44	
Water	Measure 0·375 pint.	8·45	..	30·0	..	45	
	Weight 0·45 lb.	..	9·37	..	10·8	46	
When Moulded	Oct. 3, 1867.	..	9·38	..	11·4	47	
		..	9·42	..	12·0	48	
When Tested	Oct. 3, 1868.	..	9·38	..	11·0	49	
		..	9·37	..	11·0	50	
		8·43	9·38	30·28	11·24	Average.	

C SERIES.—CEMENT BRICKS—*continued.*

PORTLAND CEMENT BRICKS (9″ × 4½″ × 3″)—Neat, and with different Proportions of Sand, tested by Crushing in Hydraulic Press.

Weight of one Bushel of Cement, 110·56 lbs.

PROPORTION OF SAND, 7 to 1.

—	Weight of each Brick, being the average of Five after being kept One Year.		Broke at Tons.		Number of Test.	Remarks.
	In Air.	In Water.	In Air.	In Water.		
	lbs.	lbs.				
Cement {Measure 0·48 pint.	7·74	..	8·9	..	31	Not Compressed.
Cement {Weight 0·84 lb.	7·84	..	8·4	..	32	
Sand {Measure 3·44 pints.	7·82	..	9·0	..	33	
Sand {Weight 6·64 lbs.	7·90	..	9·0	..	34	
Water {Measure 0·875 pint.	7·90	..	9·8	..	35	
Water {Weight 1·05 lb.	..	8·69	..	4·0	36	
When Moulded } Sept. 25, 1867.	..	8·67	..	3·2	37	
	..	8·67	..	4·2	38	
When Tested } Sept. 26, 1868.	..	8·71	..	4·8	39	
	..	8·77	..	5·1	40	
	7·84	8·705	9·05	4·26	Average.	
Cement {Measure 0·52 pint.	8·40	..	28·6	..	31	Compressed.
Cement {Weight 0·90 lb.	8·38	..	28·2	..	32	
Sand {Measure 3·71 pints.	8·40	..	28·8	..	33	
Sand {Weight 7·15 lbs.	8·42	..	28·8	..	34	
Water {Measure 0·375 pint.	8·41	..	30·0	..	35	
Water {Weight 0·45 lb.	..	9·37	..	10·5	36	
When Moulded } Oct. 3, 1867.	..	9·35	..	11·2	37	
	..	9·42	..	10·4	38	
When Tested } Oct. 3, 1868.	..	9·39	..	10·4	39	
	..	9·35	..	10·2	40	
	8·40	9·37	28·88	10·54	Average.	

PROPORTION OF SAND, 8 to 1.

Cement {Measure 0·43 pint.	7·70	..	8·0	..	21	Not Compressed.
Cement {Weight 0·74 lb.	7·70	..	7·0	..	22	
Sand {Measure 3·44 pints.	7·75	..	6·7	..	23	
Sand {Weight 6·63 lbs.	7·62	..	6·9	..	24	
Water {Measure 0·875 pint.	7·70	..	6·7	..	25	
Water {Weight 1·05 lb.	..	8·60	..	2·3	26	
When Moulded } Sept. 24, 1867.	..	8·55	..	2·2	27	
	..	8·56	..	2·6	28	
When Tested } Sept. 25, 1868.	..	8·55	..	2·2	29	
	..	8·55	..	2·3	30	
	7·694	8·562	7·06	2·32	Average.	

C Series.—CEMENT BRICKS—*continued.*

Portland Cement Bricks (9″ × 4½″ × 3″)—Neat, and with different Proportions of Sand, tested by Crushing in Hydraulic Press.

Weight of one Bushel of Cement, 110·56 lbs.

Proportion of Sand, 8 to 1—*continued.*

——	Weight of each Brick, being the average of Five after being kept One Year.		Broke at Tons.		Number of Test.	Remarks.
	In Air.	In Water.	In Air.	In Water.		
	lbs.	lbs.				
Cement {Measure 0·46 pint.	8·33	..	19·4	..	21	Compressed.
Cement {Weight 0·80 lb.	8·34	..	19·0	..	22	
Sand {Measure 3·75 pints.	8·35	..	18·8	..	23	
Sand {Weight 7·24 lbs.	8·32	..	19·0	..	24	
Water {Measure 0·375 pint.	8·32	..	19·0	..	25	
Water {Weight 0·45 lb.	..	9·42	..	8·2	26	
When Moulded } Oct. 2, 1867.	..	9·50	..	8·1	27	
	..	9·43	..	8·2	28	
When Tested } Oct. 2, 1868.	..	9·40	..	8·4	29	
	..	9·40	..	8·0	30	
	8·33	9·43	19·24	8·18	Average.	

Proportion of Sand, 9 to 1.

——	In Air.	In Water.	In Air.	In Water.	Number of Test.	Remarks.
Cement {Measure 0·39 pint.	7·70	..	5·4	..	11	Not Compressed.
Cement {Weight 0·66 lb.	7·70	..	5·2	..	12	
Sand {Measure 3·48 pints.	7·68	..	5·2	..	13	
Sand {Weight 6·72 lbs.	7·70	..	5·5	..	14	
Water {Measure 0·875 pint.	7·65	..	5·3	..	15	
Water {Weight 1·05 lb.	..	8·55	..	2·2	16	
When Moulded } Sept. 24, 1867.	..	8·54	..	2·2	17	
	..	8·54	..	2·2	18	
When Tested } Sept. 24, 1868.	..	8·56	..	2·5	19	
	..	8·54	..	2·5	20	
	7·686	8·546	5·32	2·32	Average.	
Cement {Measure 0·42 pint.	8·38	..	17·8	..	11	Compressed.
Cement {Weight 0·73 lb.	8·32	..	17·6	..	12	
Sand {Measure 3·82 pints.	8·40	..	17·8	..	13	
Sand {Weight 7·36 lbs.	8·30	..	17·0	..	14	
Water {Measure 0·375 pint.	8·39	..	17·4	..	15	
Water {Weight 0·45 lb.	..	9·24	..	7·5	16	
When Moulded } Oct. 2, 1867.	..	9·26	..	7·4	17	
	..	9·26	..	7·5	18	
When Tested } Oct. 2, 1868.	..	9·23	..	7·2	19	
	..	9·27	..	7·5	20	
	8·36	9·25	17·52	7·42	Average.	

C Series.—CEMENT BRICKS—*continued.*

Portland Cement Bricks (9″ × 4½″ × 3″)—Neat, and with different Proportions of Sand, tested by Crushing in Hydraulic Press.

Weight of one Bushel of Cement, 110·56 lbs.

Proportion of Sand, 10 to 1.

—	Weight of Five Moulds after being kept One Year. In Air.	Weight of Five Moulds after being kept One Year. In Water.	Broke at Tons. In Air.	Broke at Tons. In Water.	Number of Test.	Remarks.
	lbs.	lbs.				
Cement {Measure 0·36 pint.	7·64	..	4·50	..	1	Moulds filled in the ordinary way, without Compression.
Cement {Weight 0·60 lb.	7·60	..	4·60	..	2	
Sand {Measure 3·52 pints.	7·56	..	4·50	..	3	
Sand {Weight 6·79 lbs.	7·64	..	5·40	..	4	
Water {Measure 0·875 pint.	7·64	..	5·00	..	5	
Water {Weight 1·05 lb.	..	8·80	..	2·50	6	
When Moulded } Sept. 23, 1867.	..	8·82	..	2·50	7	
	..	8·70	..	2·20	8	
When Tested } Sept. 23, 1868.	..	8·65	..	2·10	9	
	..	8·80	..	2·10	10	
	7·616	8·754	4·80	2·28	Average.	
Cement {Measure 0·39 pint.	8·23	..	14·6	..	..	Moulds filled and Compressed by ramming.
Cement {Weight 0·66 lb.	8·27	..	16·6	..	..	
Sand {Measure 3·84 pints.	8·30	..	16·6	..	..	
Sand {Weight 7·41 lbs.	8·27	..	15·0	..	..	
Water {Measure 0·375 pint.	8·30	..	15·0	..	..	
Water {Weight 0·45 lb.	..	9·30	..	5·5	..	
When Moulded } Oct. 1, 1867.	..	9·25	..	5·0	..	
	..	9·31	..	5·5	..	
When Tested } Oct. 1, 1868.	..	9·32	..	5·7	..	
	..	9·33	..	6·4	..	
	8·27	9·30	15·44	5·62	Average.	

D Series.—CONCRETE BLOCKS.

Portland Cement Concrete Blocks of various Materials, set and kept in Air for One Year, also set and *kept in Water* for the same time.

Table I.

Material—Ballast.
Size of Block—12″ × 12″ × 12″. Compressed.

Proportion.	Weight in lbs.			Weight of each Block in lbs.		Crushed at Tons.		Remarks.
	Cement.	Sand.	Water.	Kept in Air.	Kept in Water.	Air.	Water.	
1 to 1	59·36	66·96	16·00	137·60	147·25	107·0*	170·50	* Exceptional.
2 „ 1	42·64	96·40	12·00	142·60	152·50	149·0	160·0	
3 „ 1	32·00	108·56	10·00	145·25	152·25	113·0	115·50	
4 „ 1	25·84	116·96	8·80	145·75	152·50	103·0	108·50	
5 „ 1	21·28	120·24	8·00	142·10	150·95	89·0	99·50	
6 „ 1	18·08	122·48	8·00	141·56	150·00	80·50	91·0	
7 „ 1	15·84	125·04	7·60	141·70	150·20	75·0	80·50	
8 „ 1	14·08	127·04	7·60	142·30	150·80	61·50	76·0	
9 „ 1	12·64	128·64	7·20	142·10	151·50	54·0	68·50	
10 „ 1	11·36	128·88	6·80	142·00	150·00	48·50	48·0	

Table II.

Material—Ballast.
Size of Block—6″ × 6″ × 6″. Compressed.

1 to 1	7·42	8·37	2·00	17·50	18·04	38·0	33·60	
2 „ 1	5·33	12·05	1·50	17·78	18·97	43·0	34·50	
3 „ 1	4·00	13·57	1·25	18·28	19·35	30·0	35·50	
4 „ 1	3·23	14·62	1·10	18·28	18·71	30·0	28·00	
5 „ 1	2·66	15·03	1·00	18·26	18·98	24·50	35·50	
6 „ 1	2·26	15·31	1·00	17·90	18·60	20·40	19·60	
7 „ 1	1·98	15·63	·95	17·85	18·85	16·50	16·0	
8 „ 1	1·76	15·88	·95	17·86	18·90	13·50	13·50	
9 „ 1	1·58	16·08	·90	17·78	19·0	12·0	11·00	
10 „ 1	1·42	16·11	·85	17·68	18·70	10·50	10·50	

Table III.

Material—Ballast.
Size of Block—6″ × 6″ × 6″. Not Compressed.

1 to 1	7·12	8·04	1·92	16·44	17·60	30·0	37·50	
2 „ 1	4·90	11·09	1·38	17·57	18·03	38·50	36·00	
3 „ 1	3·56	12·11	1·11	17·75	18·98	24·0	28·00	
4 „ 1	2·85	12·92	·97	17·84	18·28	28·0	27·00	
5 „ 1	2·33	13·18	·87	17·90	18·73	24·0	23·50	
6 „ 1	2·00	13·49	·88	17·35	18·30	18·20	17·00	
7 „ 1	1·77	14·02	·85	17·32	17·90	14·0	12·50	
8 „ 1	1·60	14·51	·85	17·38	17·95	12·50	11·00	
9 „ 1	1·43	14·59	·80	17·40	17·97	10·0	9·00	
10 „ 1	1·26	14·35	·75	17·20	17·50	8·0	7·00	

D Series.—CONCRETE BLOCKS—*continued.*

Portland Cement Concrete Blocks of various Materials, set and kept in Air for One Year, also set and *kept in Water* for the same time.

Table IV.

Materials—Various.
Size of Block—12″ × 12″ × 12″. Compressed.

Proportion.	Weight in lbs.			Weight of each Block in lbs.		Crushed at Tons.		Remarks.
	Cement.	Sand.	Water.	Kept in Air.	Kept in Water.	Air.	Water.	
6 to 1	18·08	122·48	8·00	141·56	150·0	80·50	91·0	Ballast.
	19·20	102·40	11·60	127·80	140·50	118·0	138·50	Portland stone.
	18·48	116·48	10·40	143·50	147·54	113·20	96·50	Granite.
	17·28	106·64	14·00	128·95	139·45	109·20	136·50	Pottery.
	16·88	98·32	12·80	122·50	131·54	110·50	111·0	Slag.
	16·24	111·28	11·60	131·90	141·33	116·00	126·0	Flints.
	18·96	124·08	10·40	147·70	155·50	99·00	112·50	Glass.

Table V.

Materials—Various.
Size of Block—12″ × 12″ × 12″. Compressed.

8 to 1	14·08	127·04	7·60	142·30	150·80	61·50	76·0	Ballast.
	14·88	106·08	13·20	130·00	140·30	110·0	126·50	Portland stone.
	12·24	116·56	10·00	140·20	144·68	73·80	84·60	Granite.
	13·12	108·24	12·80	127·40	136·20	97·50	118·0	Pottery.
	12·80	98·96	12·00	114·60	127·85	85·20	70·0	Slag.
	12·48	114·24	10·40	133·10	140·12	103·50	117·50	Flints.
	14·56	126·32	9·20	143·20	153·23	65·0	94·0	Glass.

Table VI.

Materials—Various.
Size of Block—12″ × 12″ × 12″. Compressed.

10 to 1	11·36	128·88	6·80	142·0	150·0	48·50	48·0	Ballast.
	12·16	108·48	14·88	128·0	143·10	72·60	78·0	Portland stone.
	9·84	116·82	9·20	139·85	142·80	49·80	60·50	Granite.
	10·72	110·00	11·60	126·80	136·00	90·0	100·0	Pottery.
	10·24	99·68	11·20	113·25	124·80	60·0	52·0	Slag.
	10·08	114·96	10·20	130·00	141·00	70·0	98·0	Flints.
	11·84	129·28	8·40	143·30	152·10	53·0	75·0	Glass.

D Series.—CONCRETE BLOCKS—*continued.*

Portland Cement Concrete Blocks of various Materials, set and kept in Air for One Year, also set and *kept in Water* for the same time.

Table VII.

Materials—Various.
Size of Block—6″ × 6″ × 6″. Compressed.
When Moulded, Nov. 4, 1867. When Tested, Nov. 4, 1868.

Proportion.	Weight in lbs.			Weight of each Block in lbs.		Crushed at Tons.		Remarks.
	Cement.	Sand.	Water.	Kept in Air.	Kept in Water.	Air.	Water.	
6 to 1	2·26	15·31	1·00	17·90	18·60	20·40	19·60	Ballast.
	2·40	12·80	1·45	16·90	17·67	40·60	34·50	Portland stone.
	2·31	14·56	1·30	18·53	18·88	30·50	27·0	Granite.
	2·16	13·33	1·75	16·10	17·50	28·80	26·50	Pottery.
	2·11	12·29	1·60	15·08	16·61	23·0	23·50	Slag.
	2·03	13·91	1·45	16·50	17·65	20·50	24·00	Flints.
	2·37	15·51	1·30	18·50	19·25	28·0	23·00	Glass.

Table VIII.

Materials—Various.
Size of Block—6″ × 6″ × 6″. Compressed.
When Moulded, Nov. 6, 1867. When Tested, Nov. 6, 1868.

8 to 1	1·76	15·88	·95	17·86	18·90	13·50	13·50	Ballast.
	1·86	13·26	1·65	16·32	17·50	33·00	29·00	Portland stone.
	1·53	14·57	1·25	18·10	19·00	19·60	16·00	Granite.
	1·64	13·53	1·60	16·15	16·95	22·00	23·00	Pottery.
	1·60	12·37	1·50	14·20	15·91	19·50	13·40	Slag.
	1·56	14·28	1·30	16·45	17·62	17·50	20·00	Flints.
	1·82	15·79	1·15	18·00	18·93	18·00	17·50	Glass.

Table IX.

Materials—Various.
Size of Block—6″ × 6″ × 6″. Compressed.
When Moulded, Nov. 8, 1867. When Tested, Nov. 9, 1868.

10 to 1	1·42	16·11	·85	17·68	18·70	10·50	10·50	Ballast.
	1·52	13·56	1·86	16·44	17·90	22·0	16·50	Portland stone.
	1·23	14·60	1·15	17·60	18·50	15·50	12·40	Granite.
	1·34	13·75	1·45	16·09	16·80	18·50	19·00	Pottery.
	1·28	12·46	1·40	14·00	15·50	10·50	10·00	Slag.
	1·26	14·37	1·15	16·15	17·60	15·00	18·50	Flints.
	1·48	16·16	1·05	17·90	18·73	12·50	12·80	Glass.

D Series.—CONCRETE BLOCKS—*continued.*

Portland Cement Concrete Blocks of various Materials, set and kept in Air for One Year, also set and *kept in Water* for the same time.

Table X.

Materials—Various.
Size of Block—6″ × 6″ × 6″. Not Compressed.

Proportion.	Weight in lbs.			Weight of each Block in lbs.		Crushed at Tons.		Remarks.
	Cement.	Sand.	Water.	Kept in Air.	Kept in Water.	Air.	Water.	
6 to 1	2·00	13·49	·88	17·35	18·30	18·20	17·00	Ballast.
	2·23	11·91	1·35	15·70	17·12	30·00	23·0	Portland stone.
	1·98	12·55	1·12	17·40	18·30	24·50	15·50	Granite.
	1·91	11·78	1·54	15·85	17·00	24·60	24·00	Pottery.
	1·95	11·36	1·23	14·80	15·77	20·00	19·20	Slag.
	1·76	12·11	1·26	15·20	16·60	15·50	15·50	Flints.
	2·04	13·35	1·11	17·76	18·40	16·50	17·00	Glass.

Table XI.

Materials—Various.
Size of Block—6″ × 6″ × 6″. Not Compressed.

8 to 1	1·60	14·51	·85	17·38	17·95	12·50	11·00	Ballast.
	1·70	12·15	1·51	15·63	17·00	24·50	19·50	Portland stone.
	1·31	12·53	1·07	17·45	18·20	14·50	13·40	Granite.
	1·43	11·83	1·40	15·71	16·70	18·00	18·00	Pottery.
	1·47	11·37	1·37	13·73	15·12	14·00	9·50	Slag.
	1·34	12·02	1·12	15·40	16·60	14·00	12·50	Flints.
	1·52	13·22	·96	17·30	17·80	13·60	11·40	Glass.

Table XII.

Materials—Various.
Size of Block—6″ × 6″ × 6″. Not Compressed.

10 to 1	1·26	14·35	·75	17·20	17·50	8·00	7·00	Ballast.
	1·38	12·34	1·69	16·15	17·00	19·00	10·00	Portland stone.
	1·06	12·62	·99	16·97	17·63	11·50	11·00	Granite.
	1·15	11·88	1·25	15·66	16·50	14·00	17·00	Pottery.
	1·17	11·43	1·28	13·75	15·00	8·50	5·50	Slag.
	1·13	12·00	·90	15·12	16·60	12·80	11·00	Flints.
	1·22	13·31	·86	16·95	17·70	10·00	10·80	Glass.

D Series.—CONCRETE BLOCKS—*continued.*

Portland Cement Concrete Blocks of various Materials, set and kept in Air for One Year, also set and *kept in Water* for the same time.

Table XIII.

Materials—Various.
Size of Block—6″ × 6″ × 6″.

Proportion.	Weight of Cement. lbs.		Weight of Sand, &c. lbs.		Weight of Water. lbs.		Weight of each Block. lbs.		Crushed at Tons.		Remarks.
	Compressed.	Not Compressed.	Compressed.	Not Compressed.	Compressed.	Not Compressed.	Compressed.	Not Compressed.	Compressed.	Not Compressed.	
											Kept in Air.
6 to 1	2·26	2·00	15·31	13·49	1·00	·88	17·90	17·35	20·40	18·20	Ballast.
	2·40	2·23	12·80	11·91	1·45	1·35	16·90	15·70	40·60	30·00	Portland stone.
	2·31	1·98	14·56	12·55	1·30	1·12	18·53	17·40	30·50	24·50	Granite.
	2·16	1·91	13·33	11·78	1·75	1·54	16·10	15·85	28·80	24·60	Pottery.
	2·11	1·95	12·29	11·36	1·60	1·23	15·08	14·80	23·00	20·00	Slag.
	2·03	1·76	13·91	12·11	1·45	1·26	16·50	15·20	20·50	15·50	Flints.
	2·37	2·04	15·51	13·35	1·30	1·11	18·50	17·76	28·00	16·50	Glass.

Table XIV.

Materials—Various.
Size of Block—6″ × 6″ × 6′.

											Kept in Water.
6 to 1	2·26	2·00	15·31	13·49	1·00	·88	18·60	18·30	19·60	17·00	Ballast.
	2·40	2·23	13·80	11·91	1·45	1·35	17·67	17·12	34·50	23·00	Portland stone.
	2·31	1·98	14·56	12·55	1·30	1·12	18·88	18·30	27·00	15·15	Granite.
	2·16	1·91	13·33	11·78	1·75	1·54	17·50	17·00	26·50	24·00	Pottery.
	2·11	1·95	12·29	11·36	1·60	1·23	16·61	15·77	23·50	19·20	Slag.
	2·03	1·76	13·91	12·11	1·45	1·26	17·65	16·60	24·00	15·50	Flints.
	2·37	2·04	15·51	13·35	1·30	1·11	19·25	18·40	23·00	17·00	Glass.

Table XV.

Materials—Various.
Size of Block—6″ × 6″ × 6″.

											Kept in Air.
8 to 1	1·76	1·60	15·88	14·51	·95	·85	17·86	17·38	13·50	12·50	Ballast.
	1·86	1·70	13·26	12·15	1·65	1·51	16·32	15·63	33·00	24·50	Portland stone.
	1·53	1·31	14·57	12·53	1·25	1·07	18·10	17·45	19·60	14·50	Granite.
	1·64	1·43	13·53	11·83	1·60	1·40	16·15	15·71	22·00	18·00	Pottery.
	1·60	1·47	12·37	11·37	1·50	1·37	14·20	13·73	19·50	14·00	Slag.
	1·56	1·34	14·28	12·02	1·30	1·12	16·45	15·40	17·50	14·00	Flints.
	1·82	1·52	15·79	13·22	1·15	·96	18·00	17·30	18·00	13·60	Glass.

D Series.—CONCRETE BLOCKS—*continued.*

Portland Cement Concrete Blocks of various Materials, set and kept in Air for One Year, also set and *kept in Water* for the same time.

Table XVI.

Materials—Various.
Size of Block—6″ × 6″ × 6″.

Proportion.	Weight of Cement. lbs. Compressed.	Weight of Cement. lbs. Not Compressed.	Weight of Sand, &c. lbs. Compressed.	Weight of Sand, &c. lbs. Not Compressed.	Weight of Water. lbs. Compressed.	Weight of Water. lbs. Not Compressed.	Weight of each Block. lbs. Compressed.	Weight of each Block. lbs. Not Compressed.	Crushed at Tons. Compressed.	Crushed at Tons. Not Compressed.	Remarks.
											Kept in Water.
8 to 1	1·76	1·60	15·88	14·51	·95	·85	18·90	17·95	13·50	11·00	Ballast.
	1·86	1·70	13·26	12·15	1·65	1·51	17·50	17·00	24·50	19·50	Portland stone.
	1·53	1·31	14·57	12·53	1·25	1·07	19·00	18·20	16·00	13·40	Granite.
	1·64	1·43	13·53	11·83	1·60	1·40	16·95	16·70	23·00	18·00	Pottery.
	1·63	1·47	12·37	11·37	1·50	1·37	15·91	15·12	13·40	9·50	Slag.
	1·56	1·34	14·28	12·02	1·30	1·12	17·62	16·60	20·00	12·50	Flints.
	1·82	1·52	15·79	13·22	1·15	·96	18·93	17·80	17·50	11·00	Glass.

Table XVII.

Materials—Various.
Size of Block—6″ × 9″ × 6″.

											Kept in Air.
10 to 1	1·42	1·26	16·11	14·35	·85	·75	17·68	17·20	10·50	8·00	Ballast.
	1·52	1·38	13·56	12·34	1·86	1·69	16·44	16·15	22·00	19·00	Portland stone.
	1·23	1·06	14·60	12·62	1·15	·99	17·40	16·97	15·50	11·50	Granite.
	1·34	1·15	13·75	11·88	1·45	1·25	16·09	15·66	18·50	14·00	Pottery.
	1·28	1·17	12·46	11·43	1·40	1·28	14·00	13·75	10·50	8·50	Slag.
	1·26	1·13	14·37	12·00	1·15	·90	16·15	15·12	15·00	12·80	Flints.
	1·48	1·22	16·16	13·31	1·05	·86	17·90	16·95	12·50	10·00	Glass.

Table XVIII.

Materials—Various.
Size of Block—6″ × 6″ × 6″.

											Kept in Water.
10 to 1	1·42	1·26	16·11	14·35	·85	·75	18·70	17·50	10·50	7·00	Ballast.
	1·52	1·38	13·56	12·34	1·86	1·69	17·90	17·00	16·50	10·00	Portland stone.
	1·23	1·06	14·60	12·62	1·15	·99	18·50	17·63	12·40	11·00	Granite.
	1·34	1·15	13·75	11·88	1·45	1·25	16·80	16·50	19·00	17·00	Pottery.
	1·28	1·17	12·46	11·43	1·40	1·28	15·50	15·00	10·00	5·50	Slag.
	1·26	1·13	14·37	12·00	1·15	·90	17·60	16·60	18·50	11·00	Flints.
	1·48	1·22	16·16	13·31	1·05	·86	18·73	17·70	12·80	10·80	Glass.

TABLE 5.

CONCRETE SEWERS.

LOCALITY.	Size (internally).	Length in Feet.	Cost per Foot Lineal, irrespective of Earthworks and Adjuncts.	Remarks.	Concrete per C. Yard.	Rendering per Supl. Yard.	Concrete rendered per C. Yard.
	ft. in. ft. in.		s. d.				
Tooting	3 9×2 6	775	11 4	P. C. Concrete 6 to 1, and rendered with P.C. Cement 1 to 1.			
Bridge Road, Battersea.. ..	4 0×2 8	644	13 5	Ditto.			
Camberwell Road .	4 0×2 8	2355	10 0	Ditto, but 7 to 1.			
Falcon Brook ..	4 3×2 10	2030	14 10	Ditto, 6 to 1.			
Earl Sewer, Deptford Lower Rd.	7 1×7 1	1023	16 0	Only lower half rendered as above.			
CONCRETE AND HALF-BRICK SEWERS.							
Blackfriars Road..	4 6×3 0	3486	11 9	Half-brick in Cement, and P. C. Concrete 7 to 1.			
Newington Causeway..	4 6×3 0	1953	12 2½	Ditto.			

TABLE 6.

SEWER AT DULWICH.

REGISTER of Experiments made with Portland Cement. Form of Mould, No. 2, Table 1. Sectional Area, 2·25 Square Inches. Manufactured by Messrs. FORMBY. October 17, 1868—January 28, 1869.

Weight per Bushel.	When Moulded.	When Tested.	Days in Mould.	Averages of 5 Tests each. Broke at lbs. Neat.	Averages of 5 Tests each. Broke at lbs. 1 to 1.	Proportionate Strength of the 1 to 1 to Neat.
lbs. 118	Oct. 17	Oct. 24	7	805·2	275·8	34·25
,,	,,	Oct. 31	14	924·4	316·0	34·18
,,	Oct. 19	Nov. 9	21	982·6	388·2	39·50
,,	,,	Nov. 19	Months. 1	995·4	384·4	38·61
,,	Oct. 28	Dec. 28	2	1237·0	479·0	38·71
,,	,,	Jan. 28	3	1239·0	538·6	43·47

Table 7.

Contracts on the South Side.

Particulars of Portland Cement supplied during the last five years, with average breaking weight at seven days. Form of Mould, No. 2, Table 1. Sectional Area, 2·25 Square Inches.

Names of Manufacturers and Agents.	Quantity in Bushels.	Average Weight per Bushel.	Number of Tests.	Average Breaking Weight.
		lbs.		lbs.
Formby	31,581	118·27	550	862·01
Booth	12,464	119·75	80	846·50
Lee and Co.	512	120·00	10	839·00
Burham Brick and Cement Company	320,716	113·54	3,705	825·73
Casson and Co., Agents	5,200	114·50	58	816·80
Knight, Bevan, and Sturge ..	19,429	114·52	820	803·38
Robins and Co. (Limited) ..	68,880	118·00	620	795·31
White and Co.	60	119·00	10	791·70
Burge and Co., Agents	4,500	113·00	30	789·30
Hilton	103,453	117·17	1,300	786·99
Beaumont, Agent	40	116·00	10	765·00
Lavers, Agent	12,002	116·17	160	706·97
Weston	600	120·00	10	666·40
Young and Son, Agents ..	200	117·00	10	655·80
Coles and Shadbolt	240	107·00	10	580·00
Tingey	6,300	115·50	100	564·27
Harwood and Hatcher, Agents	3,040	117·78	30	408·03
Generally	589,217	115·23	7,505	806·63

Table 8.

Specified Standard of Portland Cement supplied by Manufacturers.

—	Breaking Weights. At per Square Inch.	Breaking Weights. On 2¼ Square Inches.
	lbs.	lbs.
Greenwich and Deptford sewers ..	222·2	500
Woolwich sewers	250	562·5
White Post Lane	”	”
The Earl, Battle Bridge, &c.	”	”
Falcon Brook	”	”
Heathwall	”	”
Southern Thames Embankment	”	”
Southwark Park	350	787·5
Bankside	”	”
Bermondsey Street, &c.	”	”
Belvedere Road, &c.	”	”
Plough Road	”	”
Putney Boundary	”	”
Kennington Park Road	”	”
Kennington and Lambeth	”	”

TABLE 9.

SIXTY Experiments on Concrete Briquettes subjected to a tensile strain. Cement weighing 112 lbs. per Bushel. Form of Mould, No. 2, Table 1. Sectional Area, 2·25 Square Inches. Average of Two in each case.

1 Month.	6 Weeks.	2 Months.	6 Months.	12 Months.	——
lbs.	lbs.	lbs.	lbs.	lbs.	
306·0	383·0	407·5	505·5	541·0	3 to 1
403·5	397·5	411·0	479·0	554·5	4 „ 1
Broke winding up.	246·0	269·5	439·0	482·0	5 „ 2
133·5	189·5	221·0	273·0	319·0	6 „ 1
159·0	186·0	215·0	280·5	368·0	7 „ 1
103·0	143·0	140·5	282·5	352·5	8 „ 1

EXTRACTS from Specification for Sewers made of Portland Cement Concrete, and Concrete lined with Brickwork.

"7. 1953 feet run of egg-shaped sewer, 4 feet 6 inches in height and 3 feet in width in the clear, half brick in thickness in Portland cement, to be surrounded with Portland cement concrete, with a 9-inch stoneware pipe under invert of sewer, as shown on Drawing No. 6 (Plate 15, Fig. 7), commencing by an existing bell-mouth at Stone's End, from thence along Newington Causeway to an existing eye opposite London Road. (See Clause 34.)

"8. 3486 feet run of egg-shaped sewer, 4 feet 6 inches in height by 3 feet in width in the clear, half brick in thickness, to be surrounded with Portland cement concrete, and a 9-inch stoneware pipe under invert of sewer, as shown on Drawing No. 7, commencing at an existing bell-mouth in Saint George's Circus, thence along Blackfriars Road, to near Blackfriars Bridge. (See Clause 34.)

"9. 2355 feet run of egg-shaped sewer, 4 feet in height and 2 feet 8 inches in width in the clear, to be in Portland cement concrete, with a 9-inch stoneware pipe under invert of sewer, as shown on Drawing No. 8 (Plate 15, Fig. 9), commencing near Wyndham Road, from thence along Camberwell Road and High Street to Cold Harbour Lane, there to be connected with the existing sewer by a vertical shaft.

"10. 1023 feet run of barrel sewer, 7 feet 1 inch inside diameter, to be in Portland cement concrete, and constructed, as shown on Drawing No. 9 (Plate 15, Fig. 10), along the line of Open Earl Sewer between Grand Surrey Canal and Deptford Lower Road. The ballast for the concrete sewers is to be clean, fine, sharp Thames ballast, or other of equal quality, to be free from clay or other earthy substances, and mixed and used in every respect as the Engineer may direct. (See Clause 33.)"

Concrete Sewers.

"33. The sewers in Camberwell Road and the Earl, shown on Drawings 8 and 9 (Plate 15, Figs. 9 and 10), are to be *entirely* constructed of Portland cement concrete, made in the proportion of three bushels of cement to one cubic yard of sand and ballast. The same kind of concrete is to be used for the entire cross section, including that which surrounds the pipe under invert. In making this concrete a box 3 feet by 3 feet by 3 feet is to be used for the ballast, and another box capable of holding three 'striked' bushels for the cement. The cement and ballast are to be turned over at least three times, and thoroughly mixed together.

"33a. The centering used for the arches is to be covered with thin sheet iron, copper, or zinc, and, if necessary, greased to ensure a smooth face for the arch. The invert below the springing line is to be rendered with Portland cement and sand, in equal proportions, and finished off half an inch thick with a smooth trowelled face. This work is to be done by a plasterer. The concrete for the arches is to be of sand and cement next the face, and wherever the face is rough it is to be touched up by a plasterer, after the centres are drawn; and left in a neat and workmanlike state. The concrete side entrances are to be formed of cement and ballast of the same proportions and quality as that for the concrete sewers, and are to be *entirely* rendered with cement half an inch thick and finished like the sewers."

Half-brick Sewers.

"34. The sewers in Newington Causeway and Blackfriars Road, Drawings 6 and 7 (Plate 15, Fig. 7), are to be of half brick in thickness, and to be surrounded by Portland cement concrete of the same proportion, and in every respect like that described in the Clause, No. 33. Below the springing line, that part of the sewer which is of concrete is to be formed first, and is to be allowed to set hard before the brickwork is commenced. The brickwork is to be entirely of the best picked and assorted No. 1 bricks, and to have a collar joint between it and the concrete of half an inch of cement."

Cement.

"37. The whole of the cement shall be Portland cement of the very best quality, ground extremely fine, weighing not less than 112 lbs. to the striked bushel, and capable of maintaining a breaking weight of 350 lbs. per square inch seven days after being made in a mould, and immersed in water during the interval of seven days. The Contractor shall at all times keep in store upon the works a supply of cement equal to at least fourteen days' requirements; and with each delivery of cement shall send to the Clerk of Works a memorandum of the number of bushels sent in, and the name of the manufacturer.

"38. The cement as hereinbefore described shall, except where otherwise specified, be mixed in the proportion of one of Portland cement to one of sand. No cement to be used which has become hard or set."

Concrete Sewer with Brick Lining.

"The concrete for the 9 feet 6 inches by 9 feet 6 inches sewer, shown on

Drawings Nos. 1 and 3 (Plate 15, Fig. 11), is to be Portland cement concrete, with a lining of brickwork $4\frac{1}{2}$ inches thick in Portland cement, the concrete to be made in the proportion of three bushels of cement to one cubic yard of sand and ballast. In making this concrete a box 3 feet by 3 feet by 3 feet is to be used for the ballast, and another box capable of holding three striked bushels for the cement. The cement and ballast are to be turned over at least three times and thoroughly mixed together. Below the springing line that part of the sewer which is of concrete is to be formed first, and is to be allowed to set hard before the brickwork is commenced; the brickwork is to be entirely of the best picked and assorted No. 1 bricks, and to have a collar joint of cement half an inch in thickness between it and the concrete."

Concrete.

"40. Excepting for the 9 feet 6 inches by 9 feet 6 inches sewer, the concrete to be used throughout the works shall be Portland cement concrete, composed of clean Thames ballast or approved pit ballast, in the proportion of eight parts by measure of ballast to one part by measure of Portland cement."

Mr. J. Grant said, at this stage he would simply point out the form of moulds used in the experiments. No. 1, Table 1, was the first form, and was used previous to 1865. It would be perceived that the angles were very sharp, which was the cause of irregular fractures. After some experience the original form of mould was modified, as shown in No. 2, Table 1, in which the angles were rounded off, and which had been in use for several years. This was the form which had been used throughout the experiments described in this Paper, except where otherwise mentioned. At the same time other experiments, given in Table 1 of the Paper, were made with a variety of other moulds differing in length, shape, and sectional area. Some, instead of being broken between clips, as shown in Plate 2 of his former Paper, were broken by means of knife edges inserted in holes, as shown in Plate 4, attached to that Paper. Further experiments were made with the fiddle-shaped mould, No. 10, Table 1, which did not break uniformly at the neck; the slightest distortion making it break in a diagonal line. Some other experiments were detailed in the Paper; but these were sufficient to explain their general character.

Mr. H. E. Towle said in 1856 he was employed to take charge of works, where there had been a large quantity of the American Rosendale cement in store for a long time; and it became a question whether it should be used or rejected. It was determined that experiments should be made to ascertain the character of the cement, and some curious results were developed. This cement, in the United States, corresponded to the Portland cement of England. He tried the cement with various proportions of sand and lime paste, making up eight batches altogether. In making these experiments he desired to ascertain what effect working and re-working the mortar had upon its strength. He tried the mortar re-mixed daily for twenty days, and daily stuck bricks together transversely, and after five months pulled them apart, measuring the strain as carefully as possible. In these experiments he found it advisable to make a distinction between cohesion and adhesion. Cohesion was the quality which made the particles of a substance stick together between themselves; adhesion was the force which united the material to something else. Now, if bricks or stones were stuck together with mortar which did not

adhere to the brick as strongly as it did to itself, all expense in making the component parts of that mortar more cohesive was wasted; and therefore there was a limit to the expense to be incurred for this purpose. Reverting to the re-mixing of the mortar, he found that the maximum strength was obtained after ten times mixing and re-mixing. He certainly did not advocate mixing and re-mixing twenty or any other number of times; nevertheless this fact about this particular kind of hydraulic mortar might serve as a suggestion to others endeavouring to render the subject less obscure. Newark Rosendale cement was sold in barrels of a capacity of 4 cubic feet, and each barrel contained on an average 300 lbs. of cement. The weight of the barrels when empty averaged 25 lbs. each. A weight of 300 lbs. of Rosendale cement required $1\frac{95}{100}$ cubic foot of water to reduce it to a stiff paste, and produced $3\frac{6}{10}$ cubic feet of pure cement mortar in a state of stiff paste, weighing 117 lbs. per cubic foot. The volume of 300 lbs. of cement unpressed was $4\frac{3}{4}$ cubic feet; and as sold in the barrels 4 cubic feet.

1 Barrel Rosendale cement	4	cubic feet.
1 Box lime paste, 2 feet by 2 feet by $\frac{3}{4}$ foot	3	„
5 Boxes sand, damp and loose	15	„
Total	22	

produced a batch of 17 cubic feet of good mortar, weighing 124 lbs. per cubic foot:

Lime paste weighed, per cubic foot ..	84 lbs.
Cement „ „ ..	117 „

A block of unslaked lime 1 cubic foot in volume weighed $91\frac{43}{100}$ lbs., and when slaked by the addition of water, and reduced to a thick paste, the volume increased to $3 \cdot 047$ cubic feet. A bushel of this lime, as purchased coarse and fine together, weighed 75 lbs., and when reduced to a state of stiff paste increased in volume to $2\frac{193}{1000}$ bushels.

Lieut.-Colonel Scott, R.E., remarked that Mr. Grant had brought up the strength of Portland cement to a pitch which a few years ago was thought impossible; but he was not quite certain that in carrying it so far danger might not be incurred which at first sight might hardly be suspected. Persons who

were in the habit of using large quantities of Portland cement were aware that at times it expanded to an extraordinary degree. This was due generally to too large a quantity of chalk having been used in its preparation. A few years ago, on examining some cases where great strength was aimed at by the manufacturer, he found that where the clay was reduced to 18 or 19 per cent. instead of 22 or 23 per cent. very extraordinary expansion occurred. By the exposure of such cement to the air, the tendency to expand might be, no doubt, greatly modified, but by demanding cement of extreme strength Engineers undoubtedly ran into this danger. With a large proportion of clay there was greater safety, though somewhat less strength. A remark had been made that it was of no use getting the cohesive strength of the cement greater than the adhesion of the cement to the materials that were to be joined together by it. If that were right, and in the use of Portland cement the strength of the bricks in ordinary use was exceeded, he thought Engineers might be content to go no farther and avoid the danger he had pointed out. As to the instance cited of cement mortar when beaten up afresh, though first losing strength, afterwards becoming stronger again, he thought it might be explained by assuming that the cement might have contained some particles which had an expansive tendency. In using hydraulic lime-mortar the lime was slaked, and thus was obtained a hydrate of lime mixed with sand, and in the work a solidification occurred, partly from the action of the atmosphere and partly from the slaked lime entering into fresh combination with the silex, thus forming slowly a hydrated silicate without expansion; but if particles of unslaked lime were mingled with this, inequality of action resulted, inasmuch as the particles of unslaked and slaked lime were in a different condition. In using lias lime, for instance, unless it was ground to a fine powder and the slaking allowed to go on some time before use, the work was apt to get distorted, because those particles which were uncombined with water expanded in the work when hydration took place and burst it. In the experiments alluded to he thought that something of this kind had occurred. There was continued expansion of some of the lime particles through slaking, till the material was brought wholly into the state of hydrated silicate of lime, when it again gained in strength by the quiet and

gradual rearrangement of the particles, such as occurred with hydraulic limes, without any disturbing element.

He now would say a few words on a subject which merited attention from Engineers. There was a new mode of using lime which had been adopted in the buildings at South Kensington. If in the ordinary slaking of lime just sufficient water was added to bring it to a dry impalpable powder, this powder would have a bulk sometimes much greater than that of the original lime, and if made into paste would, when it dried, exhibit a considerable degree of porosity. It could be imagined that if the lime, instead of being slaked, were ground to powder and induced to set as cement, with its original density, much greater strength would be attained in the solidified mortar. In the use of lime the combination with water took place first, and then subsequently the solidifying action went on. If it was hydraulic lime a silicating process was set up after slaking, and a fresh arrangement of particles took place. In the case of cements the slaking and the setting went on simultaneously, and the water entered at once into combination with the cement to form a stone-like substance. If by any means lime could be induced to combine with the water slowly, so as not to burst with the heat, a much better result would follow than from the ordinary way of using it. This, in fact, was what he had accomplished by the mode in which he was now making mortar, and his general method of procedure was as follows, the lime used at Kensington being ordinary grey lime finely ground. First of all he mixed 5 per cent. of plaster of Paris, as compared with the quantity of lime to be used, in a bucket of water, making a milk of sulphate of lime. He then threw this into the pan of a mortar-mill and added the ground lime gradually, and instead of the lime slaking as it would when treated with water only, the lime showed no symptoms of slaking, and was brought to a thin paste without any sensible increase of temperature. When that was done he added sand, and for most purposes as much as 6 parts of sand to 1 of lime. In thin brickwork he obtained far greater strength with grey lime treated in this way, with 6 parts of sand, than with Portland cement with 4 parts of sand. He did not say the same results would follow the use of grey lime in very damp situations or under water; in such situations another set of

phenomena came into play; but he spoke of cases where the carbonic action of the atmosphere was chiefly depended on to bring about the hardening of the mortar. The process he had described would not give setting property under water if the lime did not possess it before. It might indeed be thought that he destroyed the water-setting property by the plaster of Paris, which was itself soluble, but that was not the case. The quantity of plaster of Paris did not exceed 0·75 per cent. of the mortar; and in three or four weeks crystallized out in the pinhole cavities in it, where it showed itself in little crystalline spangles or plates. In proportion as the percentage of clay increased in the lime employed, so this became more suitable for mortar to be used under water. Pozzolana was at one time largely imported into this country. At that time it was not known that there were large beds of a material in England which made excellent pozzolana. He believed that with his process the pozzolana of this country would come into use. He had examined the shales of the lias beds, notably those of Leicester, and he found by the use of this material calcined, and a small quantity of common chalk lime, treated as described with a milky solution of sulphate of lime, he got under certain conditions, viz. by experiments with small blocks and by putting a few bricks together, greater strength than he could get out of Portland cement. He spoke of such instances as those mentioned only. His experiments had so far extended only to such cases. He had only to add that in using this new method of mortar-making (which he termed the selenitic method) for plastering the walls in the galleries of the Exhibition Building at South Kensington, he employed 6 parts of sand to 1 part of lime, and for the finishing coat 1 part of lime with 4 parts of sand.

Mr. Bramwell said that when, five years ago, Mr. Grant brought before the Institution a Paper on this subject,[1] and pointed strongly towards the improvement that he thought would be derived from increasing the weight of the cement, Mr. Bramwell threw doubts upon the probability of such a result, since, from experiments he had made, he believed, if the weight of the cement were alone considered, it would hold out

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[1] *Vide* 'Minutes of Proceedings Inst. C.E.,' vol. xxv., p. 136 *et seq.*

a premium for bad grinding, and that badly-ground cement meant inferior cement. He was glad to find this opinion corroborated in the present Paper: for Mr. Grant now said that, with cement of 113 lbs. per bushel when unsifted, he got a strength of 375 lbs. per square inch, but when sifted the same cement, weighing only $110\frac{1}{2}$ lbs. per bushel, gave an increase of strength reaching to as much as 427 lbs. He thought this abundantly justified what he stated five years ago, that the mere test of weight alone was a premium for bad grinding, and calculated to mislead. He also, at the same time, gave instances in which large variation of strength was occasioned by an extremely small variation in the amount of water with which the cement used in the sample was gauged. He was glad now to hear Mr. Grant state that the proportions, both of water and cement, were determined by weight in the mixing of the samples tested.

Mr. Bazalgette remarked that he could not understand how it was possible to manufacture cement of too good a quality. The improved manufacture of Portland cement up to the present time had been promoted by the careful experiments of Mr. Grant. Portland cement concrete could now be used with advantage and safety where brickwork and stonework were formerly used, thus effecting a large economy in engineering works. In the Southern Thames Embankment the cost was reduced to nearly one-third of what it would have been had the embankment continued to be constructed in brickwork behind the granite facing. A further portion of embankment was on the point of commencement on the north side of the river, and this also it was intended to construct with granite facing and concrete backing without any brickwork, which he believed, owing to the good quality at which Portland cement had now arrived, would be quite as strong, and probably would form a more homogeneous mass than if constructed in brickwork. The Paper had drawn attention to the fact that Roman cement was two-thirds the price of Portland cement, but that its strength was only one-third; therefore it was more advantageous to use Portland than Roman cement. He did not notice whether the Author had made any comparison between Portland cement and lias lime mortar; but as far as his experience went, Portland cement was so superior to the ordinary limes

used for mortar in brickwork that the cement became the cheaper material of the two. For instance, he had in his experiments added in bulk the quantity of lime required to bring it up to the same price as a less quantity of Portland cement; and he found, using it in that way in mortar, that Portland cement produced much stronger brickwork than was produced by the use of the proportionately increased quantity of lime.

He did not clearly understand the distinction drawn in the course of the discussion between adhesion and cohesion. As he understood the argument, it was contended that, with harder and better cement, its power of adhering to stone or bricks would not increase in proportion to its increased power of holding together its own particles in one mass. He was, however, of opinion that if this argument had reference to cement uniting brickwork or stone, it would be found if the face of the materials to be united were rough and absorbent, the cement could penetrate the face of the brick or stone, combine with and lay hold of it, and have the same affinity to the brick or stone as to itself; and that this power of combining the whole mass together would under such conditions increase proportionately with the increased strength of the cement, so that the adhesion and the cohesion would increase at the same time and in the same proportion. He thought therefore if the strength of the cement was increased, and the building materials to be united were suitable, both the adhesion and the cohesion would also be increased, and the whole structure strengthened. The Paper led to this practical result—that by attention to the production of good Portland cement the cost of engineering works might be reduced, particularly those of large bulk, to less than half that which had been spent upon similar works before its introduction.

Mr. W. Parkes said he had lately had the opportunity of making some experiments with Portland cement, from which he had drawn conclusions similar to those of Mr. Bramwell. Everyone who had to do with Portland cement must feel indebted to Mr. Grant for the attention he had given to the subject and the results he had made public; but though the former Paper was of great use, he found the conclusions given by Mr. Grant were also liable to great abuse. Those conclusions were apparently so simple that people who were not

altogether well versed in the subject were apt to suppose that they could test cement, and know good from bad by the simple application of the rules. He concurred with Mr. Grant that two of the qualities of good cement were high specific gravity and high tensile strength; but he thought it would be inexpedient to push those principles to extremes. Good cement was generally heavy and strong, but it did not always follow that the quality was proportionate to the weight, or to the tensile strength, or to the two combined. In the case of some Portland cement lately required for sea-work in India, the Government had, under his advice, applied for tenders from several manufacturers of repute, and the three lowest tenders were accepted. It happened that the cement supplied by those three makers differed, to some extent, in the points under consideration. One being a heavy cement weighing about 120 lbs. to the bushel, equal to a tensile strain of 800 lbs. to 1000 lbs., on a sectional area of 2·25 square inches; another weighing about 108 lbs. to the bushel which bore a strain of 600 lbs. or 700 lbs.; and the third was intermediate between the two in weight, viz. about 114 lbs. to the bushel; but the tensile strength was, on the whole, greater than that of the heavier cement. The superintendent of the works was, in the first instance, favourably disposed towards the heavier cement, with high tensile strain; but after testing it, by exposing blocks of concrete to the action of the sea during a monsoon, he was unable to say that one cement was practically better than the other, as judged by this test. Subsequently he had the means of applying another practical test, by cutting into the blocks. According to this test, he gave the preference to the first heavy cement, as being decidedly harder than the other two. As to the two others, he could not say which was the best. But on the whole there was probably no great practical difference between the three cements.

He would mention another fact, to show that weight and tensile strength did not always go together. A firm of cement manufacturers requested him to test some cement which had been condemned, and he applied the ordinary tests to it. In the first place, he weighed it, and found the weight to be $101\frac{1}{2}$ lbs. to the bushel. This was very light, and he expected to find a very weak cement; he noticed, however, one remarkable

fact in making up the test-blocks. He adopted the plan, which Mr. Grant now recommended, of using exact proportions of cement and water; but he measured the cement and water, instead of weighing them. With this light cement he found this curious result: the measure he adopted had a capacity about 50 per cent. greater than that of the test-block mould, and this quantity of heavy cement in powder was sufficient, when worked up with water, to fill the mould, and even left a little excess after the mould was filled; but with the light cement it was not enough; the contraction of bulk was greater, so that it required a larger measure of that light cement to fill the mould than it did of the heavier material. When he broke the test-blocks he was surprised at the strength—the several breaking strains were 680 lbs., 600 lbs., 600 lbs., 585 lbs., and these did not give the full strength, for they were taken out of the mould quite soft. Two other samples, which were kept in the mould till quite hard, were equal respectively to 960 lbs. and 840 lbs., which for cement of only 101 lbs. to the bushel was, he thought, very high indeed. Now, if the virtue of that cement was in proportion to its tensile strength, it was not in proportion to the weight.

He was glad to find the Author now insisted that extreme care was necessary in making these tests. Generally speaking, the makers tested their cement at their own works, and employed for that purpose a man called a sampler, who had little else to do but test the cement as it was made; and those men, from long practice, had acquired so much skill that, though they performed the operation in a very rough manner, they obtained pretty regular results. But when the cement was sent to the customer, and the customer wished to test it for himself, he necessarily employed a person of less skill to make up the test-blocks, and it was almost impossible to get consistent results. There would sometimes be a difference of 100 per cent. or 150 per cent., without any apparent cause, in the breaking strain of two bricks made from the same sample. Consistent results could only be obtained by adopting exact proportions of cement and water. He had made some experiments to illustrate this. In one experiment he used four-tenths of a pint of water for each test-block, when the breaking weight in four cases was 970 lbs., 980 lbs., 1000 lbs., and 980 lbs. After that, he made

up two more samples, mixed with a half-pint of water, instead of four-tenths of a pint, and those broke with 590 lbs. and 370 lbs. Two others, made up with nine-twentieths of a pint, broke with 750 lbs. and 375 lbs. Other experiments, giving similar results, led to the conclusion that it was most important to reduce the quantity of water to a minimum, and for this purpose to have it accurately measured. He would mention a case in which neglect of this precaution had nearly led to serious results. Part of the cement which he sent out to India had been tested by himself before shipment, and the samples broke at a little over 800 lbs. When the cement arrived at its destination, the works had been stopped for a time, and 400 tons of cement were left on hand. This was transferred to another work at Bombay, and when it arrived there the Engineer who was to employ it was directed to test the cement. The tests were made, and the results were given in a strongly-worded despatch to the India Office, stating that the cement was good for nothing; inasmuch as the tests gave as its tensile strength only 248 lbs. on the brick; and that its employment in the work would not be permitted. He thereupon recommended that some samples of the cement should be sent home for further tests. On its arrival it was found to be damaged by damp, to which it had been naturally exposed in its three voyages and various tran-shipments; nevertheless, the test-blocks made from it bore strains of 660 lbs., 690 lbs., and 800 lbs., showing that there was no great deterioration of the cement. There could be no doubt that the tests at Bombay were not made with the necessary precautions; but he was convinced that there was at present a very prevalent ignorance as to their necessity, which he hoped would be removed now that Mr. Grant had brought the weight of his authority to insist upon them. Properly employed the tests were most valuable, but in the hands of in-experienced persons they were worse than useless. He would also express his opinion, that it was a mistaken practice to record only average results. All records should give individual results, by which alone the value of the tests could be judged.

The weight test was one which also required to be applied with due precaution. The rough mode employed by the makers of shovelling the material into a bushel measure was safe enough if always carried out by the same person, and he a careful and

experienced one; but it was possible, by an almost involuntary increase of force, to increase the density 2 or 3 per cent., and by an increase such as could not be prevented by a specification, to increase it 10 or 12 per cent. The employment of a hopper, as described by Mr. Grant, was the best precaution against this source of error.

There was another point, however, in which care was required. He had alluded to some very light cement on which he had experimented. The maker had assured him that this cement, when manufactured, was of much greater density. This led him to experiment on other samples; and he found in four cases that cement taken fresh from the manufactory or from the cask was heavier by respectively $6\frac{1}{2}$ lbs., 7 lbs., $4\frac{1}{2}$ lbs., and $2\frac{3}{4}$ lbs. per bushel than it was after two or three days' exposure to the air; though in this latter state it was in better condition for employment in practical work. It was therefore necessary to specify that the density should be determined when the cement was fresh from the manufactory, and not at any subsequent time.

Mr. G. F. White observed that, as one of a numerous body of cement manufacturers, he desired to express his obligations to Mr. Grant for the continuance of his investigations into the subject of Portland cement. It was needless to say that the manufacturers themselves were anxious and critical investigators of the products they turned out, and had their attention constantly directed to their improvement. He might say that in his own works there were recorded thousands of experiments for years past on the strength of cement; but he could well understand that no trials made by a manufacturer on his own material could have for the Members of the Institution the same value as those conducted by an independent Engineer. His own observations on the subject of Roman cement enabled him to corroborate the remarks of Mr. Grant as to that material. It was the fact that even after five years this cement did not attain to a greater tensile strength than 100 to 120 lbs. on the square inch, which was less than a third of the strength of Portland cement. This sufficiently accounted for what was at one time a large manufacture having dwindled down to nothing, Portland cement having entirely superseded it. The same remark would, in great measure, apply to Medina cement, which

was but a variety of Roman cement with rather more lime in it; and which, though valuable for under-water work, where rapid setting was indispensable, had on the other hand the disadvantage which attached to all quickly crystallizing cements of attaining to only a moderate degree of ultimate hardness. He fully agreed with the Author of the Paper as to the superiority of the moulds made with curved instead of straight shoulders, as tending to reduce the inequality of the strain, and to bring the pressure of the lever more equally on the centre of the brick to be tested. With respect to the wide differences of the results obtained by different experimenters on the same cement there was no doubt that different modes of gauging were adopted by different manipulators, some using more and others less water to mix the cement. Something too might be due, in the case of long voyages, to the cement having become slow setting from staleness: but the mode of testing and the machine used were at the bottom of the difficulty, and it would be highly desirable that some rule of universal application should be adopted in order to put an end to these differences. Persons who had used Portland cement for the arches of tunnels or bridges would have noticed the milky exudation referred to by Mr. Grant in cases where there was much moisture above the arch. The appearance, indeed, was not confined to cement, but often showed itself where lime mortar was present. He considered that the milk of lime so formed was, in both cases, attributable to the mechanical action of the moisture, which released a minute quantity of the uncombined lime, and caused it to exude. If there had been an excess of lime, in the sense intended by Mr. Grant, the water would have slaked it and ruptured the brickwork; but he gathered that no bad results had followed these appearances. It was, however, a subject well worthy of further investigation. Concurring as he did in the main with Mr. Grant's conclusions, that concentration of burning and tensile strength had a direct and significant relation to one another, he still maintained that, inasmuch as cement weighing 120 and 125 lbs. to the bushel could only be obtained by the admixture of excessive proportions of lime, there was always the liability to disintegration of the mortar if any of the lime were in a free state. He could not avoid noticing the fact that the strength of the mortar made with the heavy cement did not

bear the same relation to mortar made of the light cement as the two cements did to one another when mixed pure. This seems to show that it would be fairer to test the cement with, say, 2 parts of sand in the way it was going to be used in the work, after the manner usually adopted by the French Engineers. If Mr. Grant, in addition to the other services he had rendered, could point out how good cement could be made with less fuel, and thus lighten a burden which was at present their *bête noire*, he would be conferring a lasting obligation on cement manufacturers in helping them to cheapen the cost and improve the quality of their fabrication at one and the same time.

Mr. J. A. M'Connochie inquired whether in Mr. Parkes' experiments, where unequal quantities of water were used in mixing the test-blocks, the time allowed for setting was the same in each case? It appeared to him that the time allowed for setting should be regulated by the quantity of water used, if a comparison were to be drawn from the experiments as to the relative ultimate strength of the cement. He recently had occasion to send several thousand tons of Portland cement to Bombay for the drainage works, and in the case of one shipment a similar report reached him as that referred to by Mr. Parkes, that the cement on its arrival did not stand the tests it had been subjected to before it left this country. He believed that this resulted from the cement having been put into casks before it had sufficiently cooled, and that it had consequently deteriorated during the voyage. This was of great importance in sending Portland cement to hot climates, and on its arrival it should be removed from the casks, spread out, and turned over to cool.

The result of an extended series of tests which he had made entirely confirmed Mr. Grant's conclusions, that the two important features to be sought for in Portland cement were weight and fineness; and that as cement possessing these properties was slower in setting, tests at a longer period than seven days were more satisfactory where they could be obtained, for although several samples of unequal weights might attain nearly the same strength in the seven days' test, the heavier and slower setting would ultimately be decidedly the stronger.

He had adopted a different breaking section in his test-moulds from that of Mr. Grant, retaining the same sectional area of

2·25 square inches, but disposed in a depth of 2·25 inches by 1 inch wide, in place of $1\frac{1}{2}$ inch square. He found that with this section the blocks broke in nearly all cases in the smallest section, and not at the shoulders, as so often happened even with Mr. Grant's improved Pattern.

He was surprised to find from Mr. Grant's experiments that cement mixed by hand was double the strength of that ground in a mortar-mill. He believed that this must be due to the materials having been mixed for an excessive time (thirty minutes) in the mill; if six or seven minutes were tried he expected the result would be reversed, and that the cement ground in the mill would be superior to hand-mixed.

In the case of a dock wall recently built at the Surrey Commercial Docks, he specified Portland cement for concrete block facing to weigh 116 lbs. to the bushel, with a breaking weight of 350 lbs. per square inch at seven days in water. The contractors delivered a cement procured from Messrs. Lee, Son, and Co., exceeding the specification, and weighing 120 lbs. to the bushel, with a breaking weight of 440 lbs. per square inch at seven days. Finding this to be the case he abandoned blue lias lime for the concrete backing, and substituted Portland cement concrete mixed in the proportion of 1 of cement to 12 of sand and gravel. This proved entirely satisfactory. He mentioned this as an illustration to show that the idea which had been advanced, that it was unnecessary to seek for a cement stronger than the materials to be cemented, was, even on the ground of economy, an erroneous one, as the additional cost per ton of a heavy and strong over a light and weak cement was trifling compared with the saving resulting from being able to use a greater quantity of sand with it. A valuable property of Portland cement, which had not been alluded to, was that the work executed with it scarcely ever suffered from frost.

It was to be regretted that, with one or two exceptions, the rule of thumb still so largely prevailed in the manufacture of Portland cement, and he believed that by raising the standard of quality still higher than Mr. Grant had yet done, the manufacture would be improved and cement more uniform in quality be produced.

Mr. W. Parkes replied that in all his experiments the time allowed for the cement to set had been uniformly seven days.

Lieutenant W. Innes, R.E., described some experiments on which he had been engaged. The cement used was sampled out of a large quantity supplied for War Department Works, and was of a high average weight and tensile strength. Weighed in the ordinary manner it would have been from 118 lbs. to 120 lbs. per bushel; the weights given in the following Tables were lower, having been got by sliding the cement into the measure down a piece of board. Each result given was the mean of not less than ten experiments, all due precautions having been taken with the manipulation, and the specimens broken by tension in one of Addie's machines, similar to those used by the Metropolitan Board of Works.

Table I. (p. 164) showed the tensile strength at three weeks and three months of mortars composed of cement with two parts of seven different substances, including four varieties of sand, stone-dust, clay ballast, and smiths' ashes. The whole of the sands, &c., had the grains above one-twelfth of an inch in diameter sifted out before use, to avoid the uncertainty caused by larger grains in results got from a section only $1\frac{1}{2}$ inch square. The proportion of each which would have been rejected by a sieve of 2500 meshes per square inch was inserted, to give some idea of the different degrees of fineness, but what was actually used was not so sifted. *Cæteris paribus*, coarse sand gave better results than fine, both as regards strength and bulk of mortar produced (*a* and *b*, Table I.); and of mortars attaining nearly the same ultimate strength, that made with the finest sand set the slowest (*b* and *e*, Table I.). The great difference seemingly caused by a small mixture of minute shells was very noticeable. The high results obtained with burnt clay (*g*) might probably be due to its acting as a pozzolana with the free lime in the cement. Mortar made with this substance was very coherent, and resisted the washing action of water when green better than any other; but the bulk of mortar produced from a given quantity of material was very small, and it had the disadvantage of cracking and shrinking if allowed to dry before it was well set. The low result got with the coal ashes was unexpected, and might have been due to its containing a good deal of unburnt coal-dust; this admixture, however, was not uncommon.

The two remaining Tables showed the results of experiments on the effect of coarseness of grain on the properties of cement.

TABLE I.

GIVING RESULTS of EXPERIMENTS on MORTARS of PORTLAND CEMENT and various kinds of SAND, &c., made with one Measure of the former to two of the latter.

	Sands, &c. Physical Characteristics.				100 Parts of Mortar contained			Ultimate Tensile Strength.				REMARKS.
								At Three Weeks' Immersion.		At Three Months' Immersion.		
	Per cent. of Voids dry.	Per cent. o Voids wet.	Shrinkage on wetting.	Per cent. above $\frac{1}{50}$ inch diameter	Cement.	Sand.	Water.	Lbs. per Sq. Inch.	Proportional.	Lbs. per Sq. Inch.	Proportional.	
	Neat cement.			31	141	..	39	450	1·00	529	1·00	Inserted for comparison with the other mortars.
a	38	34	6	94	38	76	18	140	·31	249	·47	A sea-sand, with roughish and uneven grain, chiefly silicious and quite clean. Mortar very short and incoherent; strength of different samples somewhat variable.
b	41	34	11	76	40	80	24	94	·21	175	·33	A silicious pit-sand, quite clean, with smooth, uniform, semi-transparent grains. Mortar somewhat "short," strength very uniform.
c	32	19	16	15	40	80	34	108	·24	248	·47	A silicious pit-sand, containing a number of minute shells and a small quantity of some orange-colouring matter; grains semi-transparent, brownish yellow, and of unequal size. Mortar rather "short"; strength tolerably uniform.
d	46	34	18	56	42	84	22	165	·37	254	·48	Portland stone-dust, a mixture of roach and whitbed; grains rough and irregular, quite clean. Mortar tolerably coherent; strength very uniform.
e	43	36	11	8	39	78	31	60	·13	193	·36	Drifted sea-sand, with pure silicious, semi-transparent, and almost colourless grains, and quite clean. Mortar rather short; strength tolerably uniform.
f	64	52	25	56	44	88	44	38	·08	91	·17	Smiths' ashes, containing, however, a good deal of unburnt coal-dust; grain rough and irregular. Mortar moderately coherent, set slowly, and apt to shrink and crack; strength very uniform.
g	50	40	17	40	48	96	39	269	·59	355	·67	Clay ballast, burnt and ground, of a pale brick-red colour, with a rough uneven grain, and containing a good deal of dust. Mortar very coherent, apt to shrink and crack; strength very uniform.

Table II. (p. 166) showed the strength at three and six months, and with from 0 to 3 parts of sand, of mortars made from cement of three degrees of fineness, viz. as received from the manufacturer, and the same after being passed through sieves of 1300 and 2500 meshes per square inch, which rejected about 20 and 30 per cent. respectively. The weight per bushel and the strength of the neat cement were both diminished by sifting, the coarsest being heaviest and strongest and the finest lightest and weakest; but when gauged with one or more parts of sand the order of strength was reversed, the fine cement giving the best results. With three parts of sand and at six months the finest cement attained ·47, whilst the coarsest attained only ·29 of their respective strengths neat at the same age.

Table III. (p. 167) showed the strength at three and six months of neat cement varying in fineness from what would all pass through a sieve of 2500 meshes per square inch down to that of which 70 per cent. would be rejected. The same cement was used for all, being first sifted and then re-mixed in the proportions given. At three months the strength increased with the quantity of coarse grains up to 40 per cent. of the latter; when the cement contained more than this proportion the results, though high, were variable; at six months the strength increased with the quantity of coarse grains up to the highest proportion tried; viz. 70 per cent. Had it not been expected that the maximum strength would have been reached with a much smaller or no proportion of coarse grains, higher proportions would have been tried, but there would have been considerable difficulty in gauging the coarse cement freed or nearly so from the fine, as it was as harsh and incoherent as so much gravel.

Supposing the results given in Tables II. and III. to be trustworthy, they would seem to indicate a necessity for modifying the present weight test and adding one for fineness, for the heaviest cements were also the coarsest (heavy cement often contained 30 per cent. of grains upwards of one-fiftieth of an inch in diameter), and coarse cement, though it gave a high tensile strength neat, did not bear sand well; so that a cement giving good results with the usual weight and strength tests might give a weaker mortar when used (as it almost always was) with sand, than one not passing the tests so well. This had an important bearing on what had been remarked on as to

TABLE II.

RESULTS of EXPERIMENTS on the effect of the Coarse Particles ($\frac{1}{50}$th of an inch and upwards in diameter) of heavy PORTLAND CEMENT.

Quality of Cement used.		Ultimate Tensile Strength at Three Months.								Ultimate Tensile Strength at Six Months.							
		Net.		1 Sand.[2] 1 Cement.		2 Sand.[2] 1 Cement.		3 Sand.[2] 1 Cement.		Net.		1 Sand.[2] 1 Cement.		2 Sand.[2] 1 Cement.		3 Sand.[2] 1 Cement.	
Fineness, &c.	Weight per Bushel.	Lbs. per Inch.	Proportion.	Lbs. per Inch.	Proportion.	Lbs. per Inch.	Proportion.	Lbs. per Inch.	Proportion.	Lbs. per Inch.	Proportion.	Lbs. per Inch.	Proportion.	Lbs. per Inch.	Proportion.	Lbs. per Inch.	Proportion.
	lbs.																
Cement as received from the manufacturers	116	504	1·00	286	·57	117	·35	103	·20	527	1·00	350	·66	229	·43	151	·29
The same passed through a sieve of 1296 meshes per square inch which rejected 20 per cent.[1]	102	457	1·00	324	·71	212	·46	143	·31	492	1·00	424	·86	281	·57	173	·35
The same passed through a sieve of 2500 meshes per square inch which rejected 30 per cent.[1]	99	449	1·00	377	·84	250	·56	173	·39	486	1·00	439	·90	323	·66	228	·47

REMARKS.—The finest cement set quickest, required most water in gauging, and gave the most coherent mortar: it gave the smallest bulk of mortar from a given quantity of materials.

[1] These percentages are given by weight.

[2] The proportions were measured in light dry powder.

TABLE III.

RESULTS of EXPERIMENTS on the effect of the Coarse Particles ($\frac{1}{50}$th of an inch and upwards in diameter) of heavy PORTLAND CEMENT.

Quality of Cement used.	Ultimate Tensile Strength in lbs. per Square Inch. Kept in Water Three Months.	Ultimate Tensile Strength in lbs. per Square Inch. Kept in Water Six Months.	REMARKS.
Neat cement, of which none was rejected by a sieve of 2500 meshes per square inch	464	492	The same cement was used for the whole series, being first all sifted and then re-mixed in the proportions shown. As received from the manufacturer it weighed about 117 lbs. per bushel, and contained more than 30 per cent. which failed to pass a sieve of 2500 meshes per square inch.
Ditto 10 per cent. ditto ditto	482	508	
Ditto 20 „ ditto ditto	499	510	
Ditto 30 „ ditto ditto	507	515	
Ditto 40 „ ditto ditto	500	520	The percentages are all given by weight.
Ditto 50 „ ditto ditto	490	525	
Ditto 60 „ ditto ditto	512	527	The ultimate chemical composition of the fine and coarse grains was almost identical.
Ditto 70 „ ditto ditto	489	535	

the doubtful advantage of a cement stronger than the building material; the advantage of such a cement should be its capacity for sand, but much of this was lost by coarseness of grain.

A specific gravity test would probably be better than the common weight test, if some convenient method of applying it were devised; or if the weight test were retained it might be applied to a sample passed through a sieve of some fixed degree of fineness; the standard would probably in such a case have to be reduced, as it seemed doubtful whether it would be possible to manufacture a fine cement of the high weight per bushel now thought necessary, though of equally fine cements the heaviest would doubtless be the best.

Mr. G. H. Phipps said he could not subscribe to the argument that there was no use in having a cement stronger than the materials to be held together, as he thought there were many cases where a material possessing that property was exceedingly useful. For instance, in brick abutments for arched bridges it was always an important matter to secure the courses from sliding horizontally upon each other at the base of the skewbacks at the springing of the arch. This, he thought, could be better secured with a cement of high cohesive power, as when considered in relation to the cross joints, as well as the horizontal ones, any fracture had to pass through a considerable quantity of the cement itself, as well as to strip it off the bricks. He thought it a great advantage to be possessed of a material combining the properties of great adhesion and cohesion, and which at the same time when reduced in strength by various admixtures of sand, could be brought down nearly to the cost of common mortar.

Mr. B. Latham observed, through the Secretary, that in considering the question of the strength and durability of cement or mortar the attention of Engineers should be directed not only to the necessity of providing a material of great cohesive strength, but also one which, when applied in certain positions, should resist the influence of certain chemical forces tending to destroy it, when the inevitable result would be a failure in the work executed. During the last two or three years he had found that sewers which had been constructed for about seventeen or eighteen years, the brickwork of which was set in various kinds of lime and cement, and in some cases in a

mixture of both, were failing, and many yards of such sewers had fallen in. On examination of those defective sewers he had found that every particle of cement or lime which had been used in the mortar had disappeared from the joints, leaving nothing but the sand to hold the work together. This failure was due to the fact that sewer-water contains a certain percentage of ammonia; the ammonia, when brought into contact with ordinary lime, was converted into nitrous and nitric acid, which, in its turn, attacked the lime, forming nitrates and nitrites, which were extremely soluble, and which were washed out either by the sewage or by the infiltration of subsoil water into the sewers, leaving nothing but the sand in the joints. Cements and limes, intended to be used in such a position as to be exposed to chemical influence, should, in addition to the tests recommended by Mr. Grant, be subjected to a standard solution of nitric acid, in order to ascertain whether or not the material was suitable for the particular class of work for which it was required. Portland cement was the best material for resisting the chemical action of sewage; on the other hand, lime made from chalk was the worst. Therefore there was a possibility of carrying the manufacture of Portland cement to such a point that, in order to secure a great tensile strength, so much chalk might be used in its manufacture as to render it unsuitable to resist the chemical action of the matters with which it might be brought into contact. He had some years ago adopted the mode of constructing sewers recommended by Mr. Grant, viz. with an internal ring of brickwork, the external portion of the sewer being formed in concrete; and during the last six or seven years he had constructed several miles of such sewers, and could bear testimony not only to their efficiency, but to their great strength and durability, and to the cheapness of their construction. In the case of a sewer at Croydon, which was 4 feet in internal diameter, the inner circle being formed of a 4½-inch ring of brickwork, and the external portion of the sewer consisting of 6 inches of concrete, the sewer was constructed at 40 per cent. less cost than would have been the case had the whole work been executed in 9-inch brickwork.

Mr. J. Grant, in reply upon the discussion, observed that Mr. Towle, Colonel Scott, and others contended that it did not follow that cement of great cohesive was necessarily of great

adhesive strength; in fact, that no advantage was gained by making cement of a strength exceeding that of the materials to be cemented together. It was with the object of settling this point that the B Series of experiments was made. In the Tables relating to that series it would be seen that the cohesive varied directly as the adhesive strength of cement; that in fact neat cement was from three to four times the adhesive strength of any mixture of it with four or five times its bulk of sand; and on this account he was prepared to state, in general terms, that cohesive and adhesive strength might be taken as equivalent to each other. For the purpose of cementing together various materials, he need hardly point out that to have strong cement or mortar was not the only thing necessary. For instance, two cubes of glass could not be cemented together, however strong the cement, so that they should adhere with the same tenacity as two bricks or blocks of stone of a porous character, and rough on their faces. It would not be possible, for example, to take such bricks as were recently used for lining the subway from the Houses of Parliament to the adjoining railway station, and to cement their highly glazed china faces together so that it would require the same pull to separate them as it would to separate two stocks, wire-cut gault, Fareham red, or other porous bricks, capable of absorbing about one-fifth part of their weight of water. Whilst on this point he might state that only second in importance, if second, to the strength of the cement was that of seeing that the bricks or stone to be cemented together were thoroughly saturated with water. In hot climates like that of India, any work being built with cement should be kept wet, and if possible under shelter during its progress and for some time afterwards. Two bricks might be put together dry as they came from the kiln with the strongest cement that could be made, and if not previously soaked in water, these bricks might be separated without the least difficulty, the joint being very little better than if made of dry sand. With bricks which absorbed from 1 lb. to 1¼ lb. of water, it was evident that if left to absorb this moisture from the mortar with which they were cemented, they took away that which was necessary for crystallizing or setting the cement.

He thought it must be self-evident that for making concrete strong cement was much to be preferred to weak. Concrete

made of absorbent material, such as broken bricks, stone, or pottery, was much stronger than concrete made of Thames ballast or any other slightly absorbent material. In the D Series of Tables it would be found that concrete made of Thames ballast was only from half to two-thirds the strength of concrete made of broken bricks, stone, or pottery. It would be found also that bricks of a somewhat porous character, like the red bricks or the wire-cut gault bricks, and the other varieties shown in Table B, adhered together with a strength double that of bricks like the Staffordshire blue bricks without a frog, or bricks that had a smooth or glazed surface.

On the point of strength it had been pointed out clearly five years ago, and again on the present occasion, that the strength of cement could always be reduced by mixing sand in any proportion.

With respect to the cement or lime mentioned by Colonel Scott, he had the pleasure of going over part of the works at South Kensington, and had also an opportunity of testing the cement in one of the large sewers where it was used in the arch; but he was sorry to say it did not answer the purpose, and was much inferior to lias lime. On a later occasion he made a number of briquettes or moulds of it, as in the case of cement; but it was so weak that it would not bear winding up in the machine. Thus either Colonel Scott was not fortunate enough to have made his comparisons with Portland cement of a good quality or he had himself been unfortunate enough to meet with an inferior sample of the lime or cement referred to. The objections raised by Mr. Parkes as to the comparative strength of cements of different specific gravities might be valid if the time allowed for the heavier cement was short; in fact, the heavier the cement the longer time it was necessary to give it to set. For experimental purposes with heavy cements a month was fairer than a week. For practical purposes, in works carried on in the streets of London, a week was a more convenient time; but for experimental purposes with different weights of cement the longer time was much more satisfactory.

As to the strength of cements generally, if it could be made of a high quality it might at any time, as he had stated, be reduced in strength. It was not unlikely at some future, though it might be far distant, time that many of the sandy districts of

Africa and other parts of the world might be irrigated by aqueducts, for the construction of which all the materials necessary would be comparatively small quantities of cement in a concentrated form, to reduce the bulk and cost of freight, mixed with the sand upon the spot.

Mr. Vignoles, President, said there was not time for him to express fully his individual opinion on this subject, and he must content himself with observing that he did not concur in all that Mr. Bazalgette and Mr. Grant had propounded, and that there was much to be said upon what had been advanced by Colonel Scott with regard to having too strong an adhesive material. He thought the subject had yet to be considered more fully.

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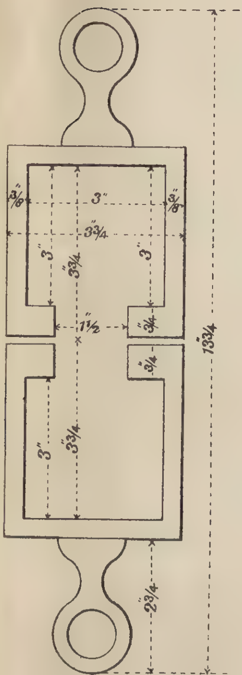
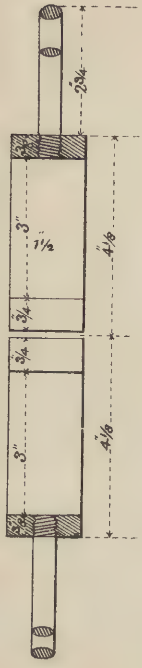
THE STRENGTH OF CEMENT. PLATE 1.

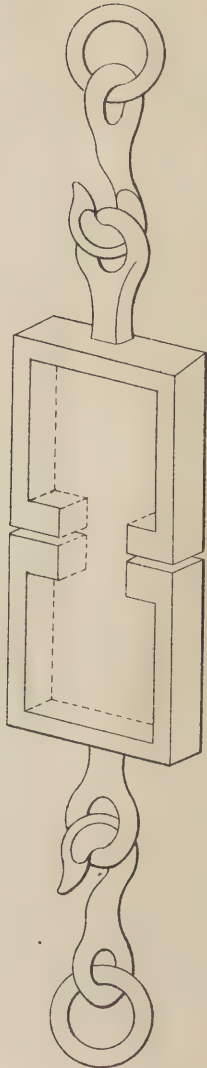
MOULD USED IN EXPERIMENTS.



ELEVATION.



SECTION.



SCALE, 3 INCHES TO THE FOOT.

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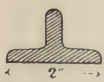
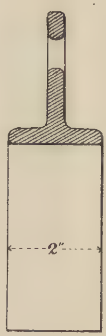
THE STRENGTH OF CEMENT.

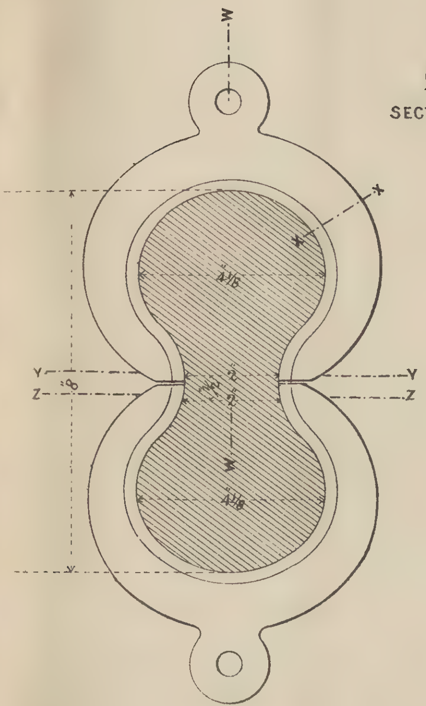
MOULD PROPOSED TO BE USED IN
FUTURE EXPERIMENTS.



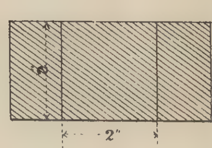
SECTION AT X.X.



SECTION AT W.W.



ELEVATION.



SECTION AT Y. Y. & Z. Z.

SCALE, QUARTER FULL SIZE.

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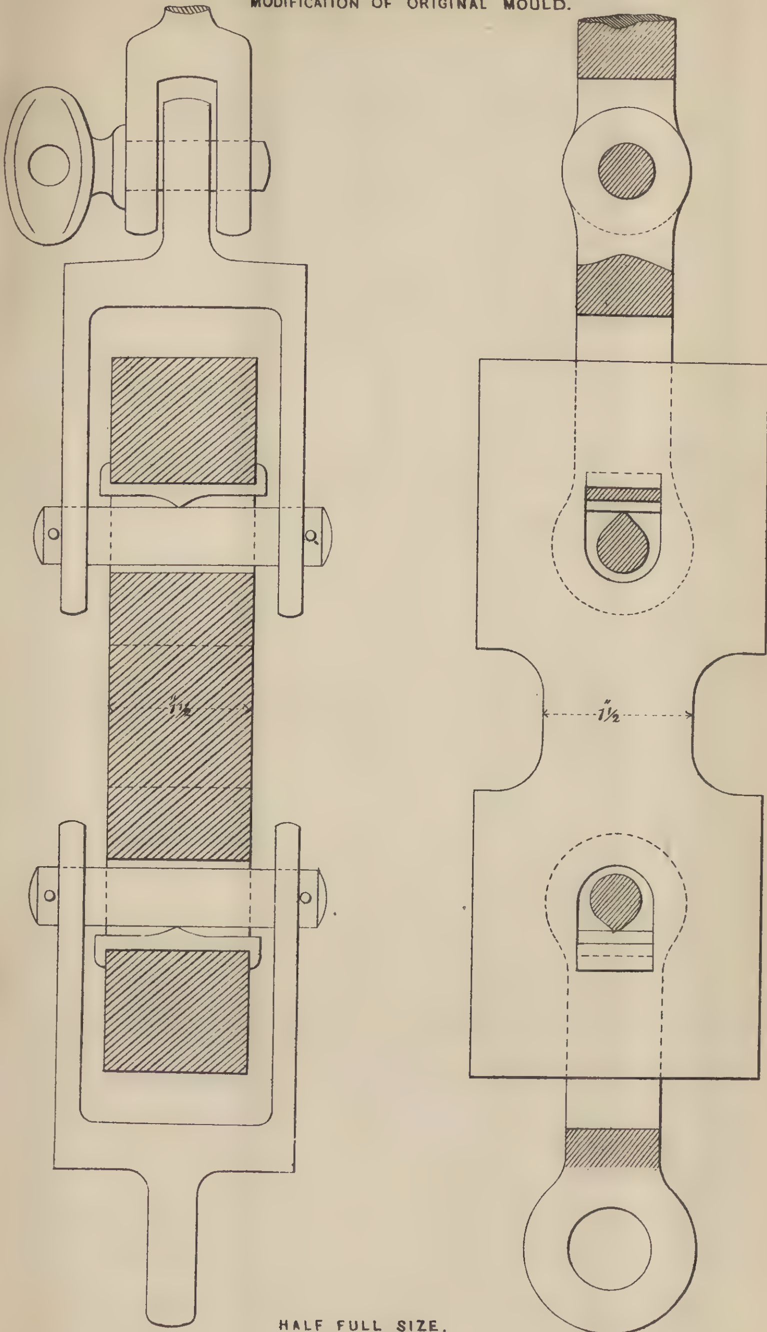
THE STRENGTH OF CEMENT.

PLATE 3.

MODIFICATION OF ORIGINAL MOULD.



HALF FULL SIZE.

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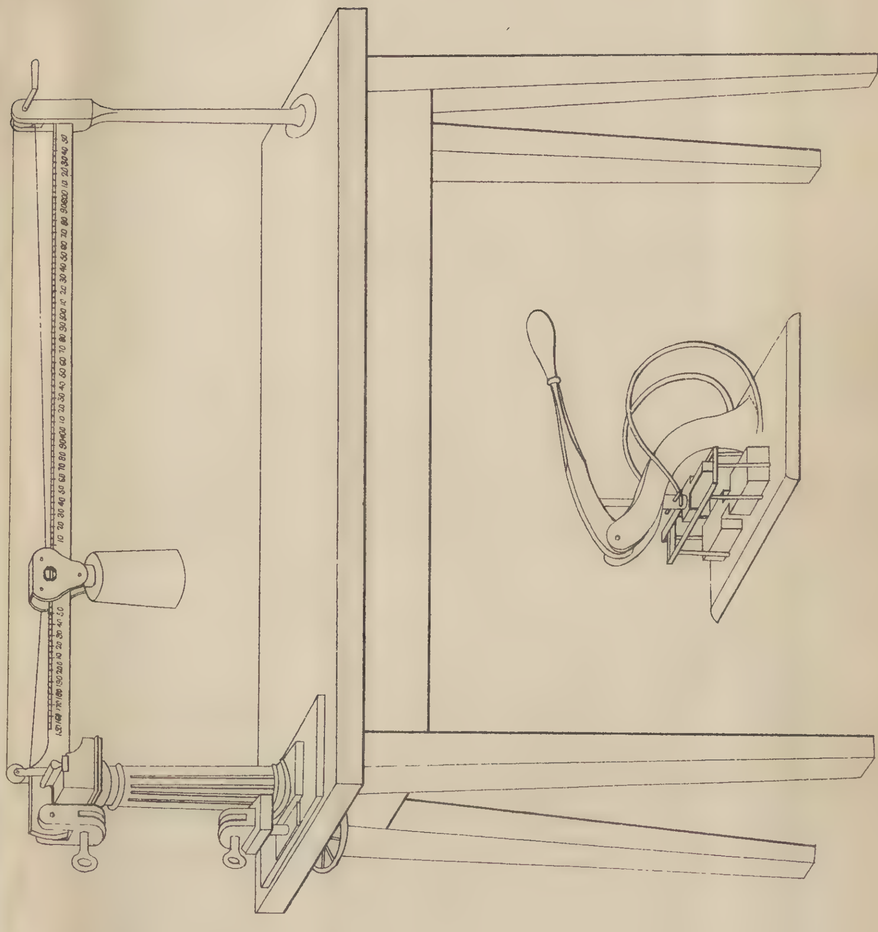
THE STRENGTH OF CEMENT. PLATE 4.

TESTING MACHINE.



Scale.

Ins. 12 9 6 3 0 1 2 3 Ft.

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THE STRENGTH OF CEMENT.

PLATE 5.

DIAGRAM TO ILLUSTRATE TABLE V. SHEWING THE AVERAGE BREAKING WEIGHT AND THE TOTAL QUANTITY OF CEMENT SUPPLIED TO EACH CONTRACT, MAIN DRAINAGE OF LONDON, SOUTH SIDE.

Note. *The Vertical Scale shews the number of lbs. at which the Cement broke, with a tensile strain, on a Sectional area of 1.5 inch × 1.5 inch = 2.25 square inches. The weight of the Cement was 114.16 lbs. per bushel. The Horizontal Scale shews the number of bushels used upon the Works.*

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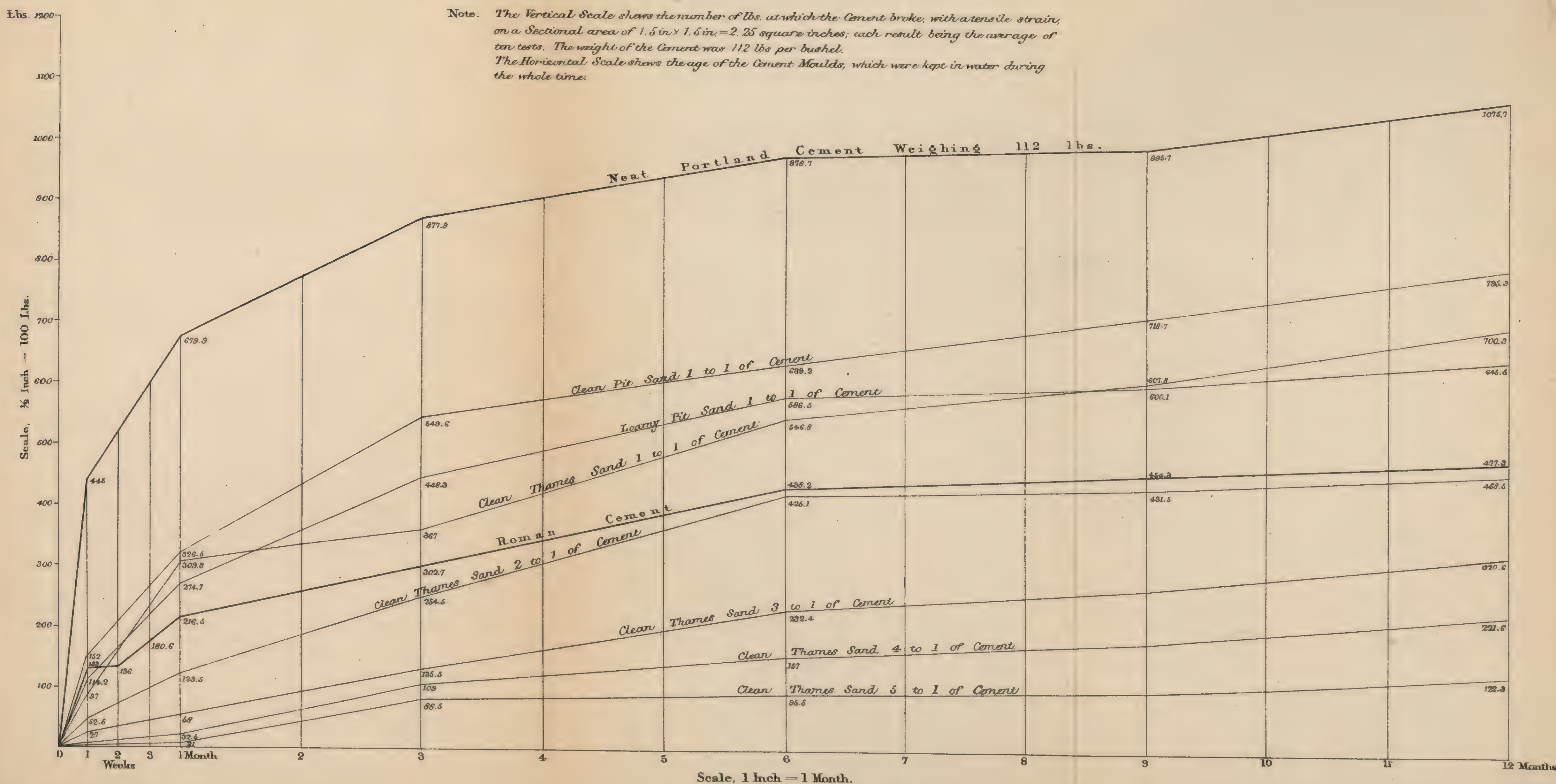
THE STRENGTH OF CEMENT.

DIAGRAM TO ILLUSTRATE TABLES XVII AND XXVII, SHEWING THE COMPARATIVE STRENGTH OF PORTLAND CEMENT WITH SAND OF DIFFERENT KINDS, AND WITH DIFFERENT PROPORTIONS, AND OF PORTLAND CEMENT AND ROMAN CEMENT OF DIFFERENT AGES.



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THE STRENGTH OF CEMENT.

DIAGRAM TO ILLUSTRATE TABLE XVIII.

Note. *The Vertical Scale shews the number of lbs. at which the Cement broke with a tensile strain, on a Sectional area of 1.5 in. × 1.5 in. = 2.25 square inches, each result being the average of ten tests. The weight of the Cement was 123 lbs. per bushel.*

The Horizontal Scale shews the age of the Cement Moulds, which were kept in water during the whole time.

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PORTLAND CEMENT

ILLUSTRATIONS OF ITS USE IN THE MAIN-DRAINAGE OF LONDON AND SOUTHERN THAMES EMBANKMENT.

Fig. 1.

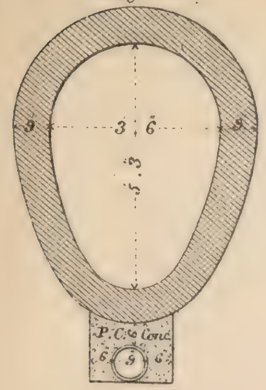


Fig. 2.

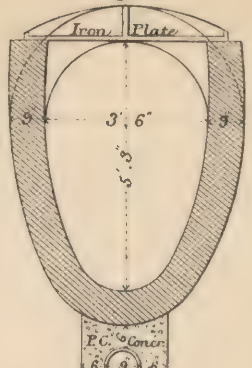


Fig. 3.

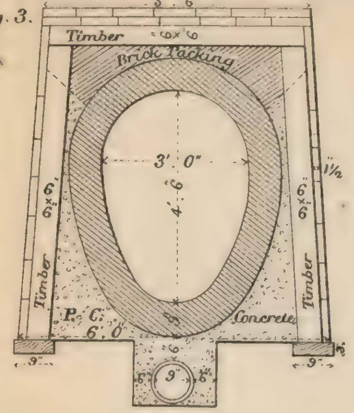
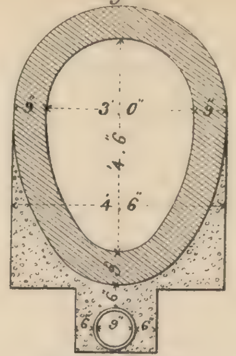


Fig. 4.



BRICK SEWER
AND CONCRETE CRADLE.

Fig. 5.

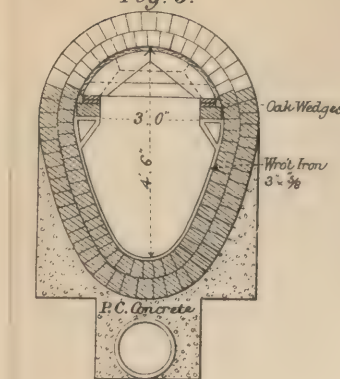


Fig. 6.

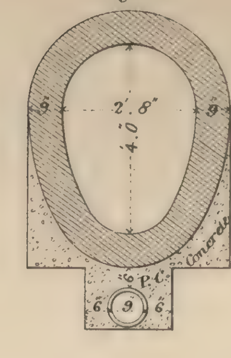
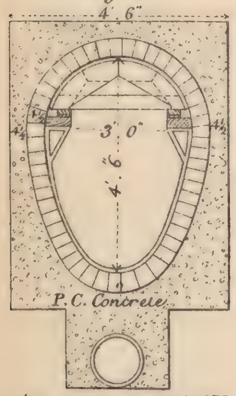
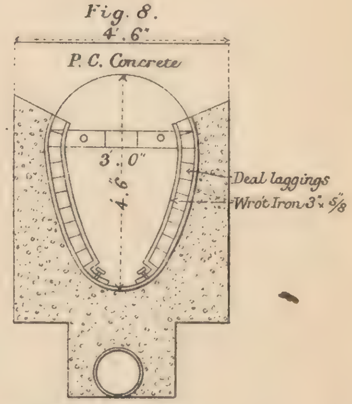


Fig. 7.



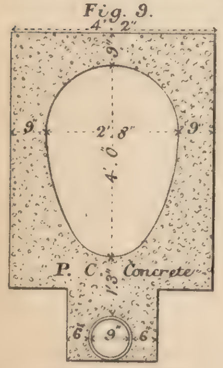
BRICK SEWER IN CONCRETE
SHEWING CENTERING.

Fig. 8.

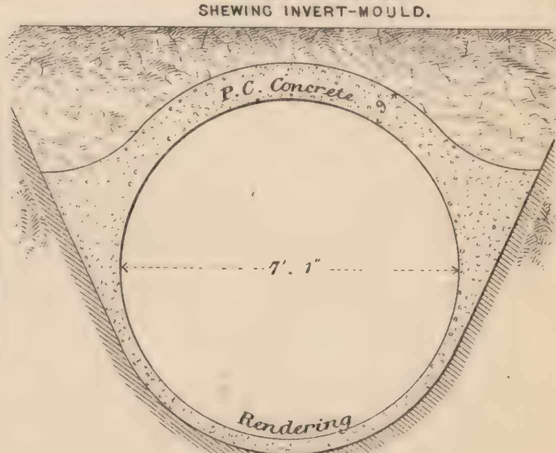


CONCRETE SEWER.
SHEWING INVERT-MOULD.

Fig. 9.

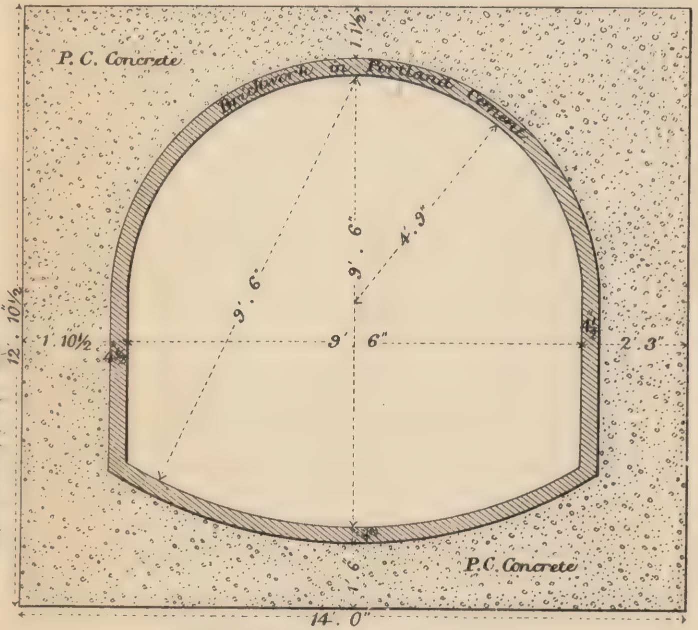


CONCRETE SEWER.



CONCRETE SEWER
EARL-DEPTFORD LOWER ROAD.

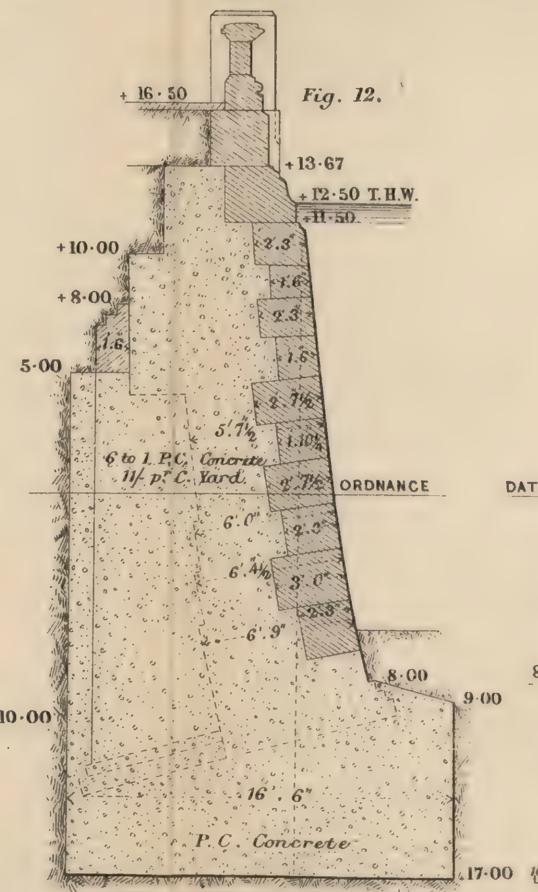
Fig. 11.



CONCRETE SEWER LINED WITH BRICK.

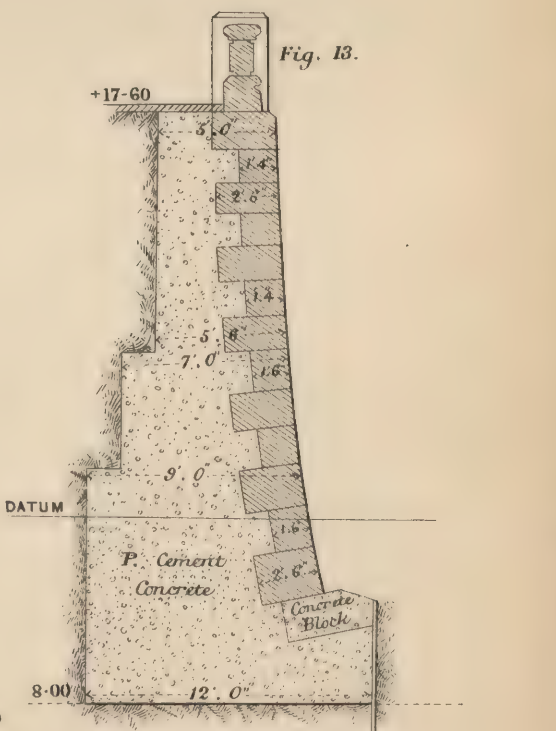
Scale for Figs. 1, 11, 4 Feet 1 Inch.

Fig. 12.



ALBERT OR SOUTHERN EMBANKMENT.
Length 4300 Feet.

Fig. 13.



CHELSEA EMBANKMENT
PORTLAND CEMENT CONCRETE, FACED WITH GRANITE.
Length 4200 Feet.

Scale for Figs. 12 & 13. 8 Feet = 1 Inch.

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